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Federal Government assistance to colleges and universities is recommended in order to make up deficiencies in educational computing facilities and to support leadership and innovation at those institutions which presently have computer facilities. By 1971, an estimated annual outlay of $400 million will be necessary to give undergraduates adequate computer services. Universities should use accounting procedures which will enable them to determine and control computer costs. The Federal Government can provide flexible support for the purchase or rental of computer equipment and services, for research and education in computer science, for faculty training in computer use; and, in cooperation with colleges, establish central computing facilities capable of serving several institutions simultaneously. A group, established jointly by the National Science Foundation and the Office of Education, is recommended to investigate and publish data on computer use in secondary schools. Statistics and forecasts concerning computers and the jobs and personnel associated with them can be made available by the Federal Government. Appendices to the report include estimates of the cost and capacity of an adequate computer service as well as data on existing computer facilities and present government expenditure in the field. (JY)

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Computers in Higher Education

Report of the
President's Science Advisory Committee

THE WHITE HOUSE
Washington, D.C.
February 1967

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U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION

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I. INTRODUCTION, FINDINGS, AND RECOMMENDATIONS

After growing wildly for years, the field of computing now appears to be approaching its infancy. Recent revolutionary technological advances will eventually take us far beyond our newest, biggest, and best computers. Yet computers and computing have already fantastically increased our power to know as well as to do. They have made masses of data which were previously completely intractable accessible to analysis and understanding. They have made it possible to trace the consequences of theories and assumptions in a wide diversity of fields.

As computers and computing have become more powerful, they have invaded wide areas of industry, government, and the professions. Computers launch and guide missiles and antimissile missiles. Computers aid in engineering design, they control machine tools and chemical processes, they keep books, control inventories, and make out payrolls. In the production of newspapers and books, computers are used in alphabetizing and correcting text, and in justifying and hyphenating lines of type. Computers are used in the retrieval of medical information and in the analysis of voluminous business, social, and historical data. Indeed, it seems that the social and economic gains which can be made through the use of computers and computing may be limited chiefly by the availability of people who are able to apply these tools in new and useful ways.

In the field of scholarship and education, there is hardly an area that is not now using digital computing. Appendix J of this report cites examples from instruction in linguistics, business and social sciences, as well as mathematics, physics, engineering, geology, and biology. Use of computing in scholarly research ranges even more broadly, and includes the analysis of literary texts and the analysis, composition, and playing of music. Computing is a new resource in learning. It enables the student or the scholar to deal with realistic problems rather than oversimplified models. By lessening the time spent in the drudgery of problem solving and in the analysis of data, it frees time for thought and insight. Partly, it enables the student to do old things more easily, but more important, it enables him to do things he otherwise could not. Computing increases the quality and scope of education.

The widespread use of computing in scholarship as well as industry and government has come about not just because of a general enthusiasm for computers, but because this new tool has found vital and increasing use in each field in which it has been applied. Appendix K presents statements from a variety of experienced people concerning the widespread applicability and value of computing in education and in business. Computers and computing are simultaneously an American resource and a challenge to America. Here indeed we have a lead on the world, a lead which gives us an intellectual as well as an industrial advantage.

If we are to exploit our opportunity fully, students in colleges and universities must see for themselves what a powerful tool computing is, and learn to use it. No matter what his specialty, the student must be given the opportunity of using computers in learning and in doing, and the faculty member must be able to use computers in teaching. Both the individual's opportunities and the progress, well-being, and stature of our society can be increased by adequate computing facilities for our colleges and universities.

Further, both in providing the necessary facilities and in meeting scientific and industrial requirements, we need more men who are deeply trained in computer science. While computers and computing supply all of scholarship and education with a new resource and a new opportunity, they also tax education and educators with new problems. It has been estimated (see App. I) that in January 1965 $7.2 billion worth of computers had been installed in this country, and the annual growth rate was estimated as 25 percent. About 185,000 college graduates were needed to use the Nation's computers. A projected annual growth of 20 percent in this number roughly equals annual engineering baccalaureates and exceeds those in mathematics or physical sciences. Computing must be available which is adequate for education in computer sciences as well as for education in other fields.

Happily, at some fortunate and forward looking colleges and universities the educational use of computers is widespread and effective. But this does not apply to the majority, where computing facilities are often absent or inadequate, or where their use is confined to a few specialties.

Can this deficit be remedied, so that no American need have second-rate education in this respect?

Because of the extremely rapid rate of change in the computer art, it is impossible to make useful long-range predictions, extending beyond the era of the new generation of powerful computers which are just coming into use. But, it is possible to estimate the cost of providing by means of these efficient new computer systems the high grade of educational use that is *now* available in *some* colleges and universities to *all* of our colleges and universities. One of the chief aims of this report is to estimate the cost of making up the deficit in educational computing and to show how the deficit can be made up while still supporting leadership and innovations in educational computing.

The recommendations we make are expensive, but if they are not carried out there will be a different kind of cost. Today, the best and richest institutions are able to carry part of the burden of educational computing. As time goes on, these institutions will improve the service they give their undergraduates, while smaller and poorer institutions will be trying to catch up. Many of them will be able to catch up to today's best in 10 or 15 years instead of the 5 years we recommend. If the deficit in educational computing is not made up quickly, millions of students who will have attended these institutions in the 1970's will be poorly prepared for the world of the 1980's and 1990's.

The answers we have arrived at are intended to apply over the period from late 1968 to late 1971. The new generation of large computers which is just coming into use will be predominant during most of this period. It will be a period during which techniques and apparatus which are now available and in limited or experimental use will become widely used. Although general computer technology will improve, we believe that during this period there will be no widespread revolutionary effects due to such advances as "microelectronics" and ultra-large memories.

The cost of providing adequate computing turns out to be large in overall magnitude, but the estimated cost of $60 per student per year averaged over all college students is comparable to the $50 to $200 per student per year for college libraries and an estimated $95 per chemistry student per year for a single chemistry laboratory course in a 4-year college. The total cost for adequate computing in connection with training in computer sciences will be a small part of the total cost of adequate computing for undergraduate education, so the average of $60 per year should provide for adequate educational use of computers in colleges and universities (exclusive of graduate research).

While the average cost of $60 per student per year is a small part (around 4 percent) of the overall educational cost per student per year, there is no place for it in the already tight budgets of America's colleges and universities. Further, the cost is growing rapidly compared with other expenses, and it must grow even more rapidly if adequate service is to be provided for all students. We believe that it is in the national interest to have adequate computing for educational use in all our institutions of higher education by 1971–72. We believe that this can be achieved, but we believe that it can be done only with government assistance.

The cost and use of computing in colleges and universities will and should be a small part of the total cost and use of computers in industry and in government.* But these major economically and socially productive uses are dependent on educational computing not only for the training of manpower, but for stimulation both in new and productive uses of computing, and in advances in computers and their software. Adequate support of computing as a part of education is essential for a rapid and full realization of the social and economic benefits of computing.

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*In 1965 the capital value of college and university computers was $300 million, or one twenty-sixth of the total of $7.8 billion for the United States (fig. 4 of App. I) and the cost of computers used in instruction $35 million, or one-two hundred twentieth of the U.S. total, according to the report "Digital Computer Needs in Universities and Colleges," (Rosser report), publication 1233, National Academy of Sciences.

While an investigation of the cost of and means for remedying our computer deficit in undergraduate education by 1971 is a chief purpose of this report, other purposes are to cast light on various opportunities and problems in the educational use of computers.

The report is divided into four main sections. The first is primarily concerned with computers and undergraduate education. The second considers education in computer sciences, mainly at the graduate level. The third discusses the interaction between research and educational use of computers. The fourth comments briefly on computers and secondary education.

The major findings and recommendations of the Panel are:

1. Approximately 35 percent of college undergraduates are enrolled in curricula in which they could make valuable use of computers in a substantial fraction of their courses. An additional 40 percent are in curricula for which introductory computing training would be very useful, and limited computer use should be part of several courses. The remaining 25 percent could make some use of computers in one or more courses during their college education, but computer training is not now important in their major studies.

In 1965 less than 5 percent of the total college enrollment, all located at a relatively few favored schools, had access to computing service adequate for these educational needs. However, it is practical to supply adequate computing service to nearly all colleges by around 1971–72.

> *We recommend* that colleges and universities in cooperation with the Federal Government take steps to provide all students needing such facilities with computing service at least comparable in quality to that now available at the more pioneering schools.

2. One of the major problems in providing the necessary educational computing is the cost. The yearly cost of providing this service will rise to a total (for baccalaureate programs and 2-year colleges) of about $400 million per year in 1971–72 in addition to the relatively smaller costs required for faculty training and associated research. It is beyond the capabilities of our colleges and universities to bear all of this cost in this time period.

> *We recommend* that colleges be encouraged to provide adequate computing through government sharing of the cost. Such governmental cost sharing should include special grants to cover transient costs when service is being initiated or larger facilities are being installed. It should also provide a portion of the annual cost of continuing service.

3. Government accounting practices have made it very difficult for colleges and universities to utilize fully that Federal and private support for

computers or computer service intended for unsponsored research and education (as distinguished from research paid for by grants and contracts).

Treatment of a grant for educational use of a computer as a reduction in total cost reduces the hourly charge for computer time paid by all users and has the effect of shifting research costs to educational users. The Department of Defense has recognized this and now has an agreement with the National Science Foundation not to treat NSF educational grants for operating expenses as a reduction in sponsored research costs.

Many schools cannot now afford to pay for educational and unsponsored research use of computers by students and faculty even though there is time available on their computers. Consequently, some college and university computers now available for educational and unsponsored research use are standing idle for major portions of the operating week.

> *We recommend* that the present DOD–NSF agreement be extended to other government agencies and private supporters and include both capital and operating cost grants. Additional Federal funds should be made available *immediately* for support of computing service used for education and unsponsored research activities at institutions *presently* having the required facilities.

4. We find that any expansion of the educational use of computing depends heavily on increased knowledge of computing by faculty in most disciplines. Such knowledge usually can be provided by intensive 2- to 6-week periods of faculty education. The extensive activity of the National Science Foundation in sponsoring summer institutes provides a useful model.

> *We recommend* an expanded faculty training program to provide adequate faculty competence in the use of computing in various disciplines.

5. There is a great need for specialists trained in the computer sciences at the bachelor's, master's, and doctorate level. The whole success of educational computing and continued improvement in its use depends on expanded education and research in computer sciences. This education requires a good faculty and access to very good computing facilities for both course work and research.

> *We recommend* that the Federal Government expand its support of both research and education in computer sciences.

6. The cost of computing is a continuing expense, like light or water, rather than a capital investment, like the initial cost of buildings.

> *We recommend* that the Government agencies which support computing allow the schools to be free to apply the funds either to the purchase or rental of equipment and the support of staff, or to the purchase of service.

7. The optimum mechanism for providing computers will differ from campus to campus. However, in many cases it appears economical and ef-

fective to supply adequate and dependable service from large computing centers.

> *We recommend* that universities and the Government cooperate in the immediate establishment of large central educational computing facilities capable of serving several institutions.

8. Because of inconsistent Government and university accounting practices, the great variety of sources of computing support, and the experimental nature of computer use, some universities have had difficulty in determining and controlling their computer costs. Informed decisions regarding expansion and/or budgeting for current operations cannot be made without accurate cost information. Errors made at this stage can only lead to the diversion and dissipation of university resources needed for other educational purposes.

> *We recommend* that universities and colleges develop and use accounting procedures which accurately measure the cost and utilization of computer services. With such information the allocation of computer time for research and education and the anticipation of associated costs should be made on a realistic and measurable basis.

9. Proper introduction of computing into secondary education is desirable and growing. Not enough is known about the best ways for introducing computing and we were not able to consider this adequately in the time available.

> *We recommend* that NSF and the Office of Education jointly establish a group which is competent to investigate the use of computers in secondary schools and to give the schools access to past and present experience. Cooperation between secondary schools and universities, and particularly providing service to secondary schools from university centers, should be encouraged.

10. There is inadequate information about the number and level of skills of personnel now employed in the field of computers, and there are no meaningful forecasts.

> *We recommend* that the Federal Government collect meaningful data concerning computers and the jobs, personnel, and educational facilities associated with them, and endeavor to make useful annual forecasts.

II. COMPUTERS AND UNDERGRADUATE EDUCATION

Computers in Colleges and Universities

Computers were first introduced into universities as rare and special pieces of equipment used for a few specialized sorts of research by small groups of people. Today, many universities and colleges have centers which serve most of the students, faculty, and administration both by providing training in programing and by meeting computing needs for undergraduate education, for research, and often for administration.

Where adequate computing facilities have been available, the faculty has made increasing use of computing in both research and education, and computing has become a part of more and more undergraduate courses, including business subjects, social sciences, biological and health sciences, psychology, geology and other disciplines, as well as mathematics, physics, chemistry, and engineering.* This is consistent with the rapidly growing use of computing outside the schools in small as well as large business enterprises, in government operations and national defense facilities, and in almost all technology—those many fields of endeavor where most college graduates will find their places. Computing is not an esoteric or specialized activity; it is a versatile tool useful in any work with a factual or intellectual content. Computing is becoming almost as much a part of our working life as doing arithmetic or driving a car.**

Computers find a widespread use in education only when well-run facilities are easily available to all students and faculty members, with rapid service for all users. Under these conditions there are a number of instances (including, for example, Dartmouth and Texas A. & M.) in which a majority of *all* undergraduates learn programing and use computing in some part of their course work. While computing has not yet become an important part of undergraduate course work in such fields as English, linguistics, languages, history, music, and art, faculty members in some of these fields are making increasing use of computers in research, and computing is beginning to find its way into undergraduate instruction.

In all fields where computing has been used, it has added a new dimension to education, and has led the students to better comprehension of complex

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*The examples given in App. J give some idea of the range of profitable use of computing in higher education.

**Apps. B, C, and E introduce some of the jargon, e.g., hardware, software and problems and greater insight into the meaning of quantitative expressions. In these areas undergraduates have learned, through preparation of and experimentation with computer programs, of the care required to define a problem logically and fully, and the assumptions needed to obtain answers to complex problems. We predict that in the future almost all undergraduates will use computers profitably *if adequate computing facilities are available.* There may be a few students in some fields who will not use computers at all, but they will be a small minority.

Using a Computer Is Easy

It is possible to make effective use of computers without programing training. "Computer aided instruction" systems and some information retrieval systems (Medlars, for instance) are examples of uses which do not require appreciable programing knowledge. There are many other examples for which the user need only supply data to existing programs.

However, acquiring some knowledge of programing is easy, and it greatly extends the scope of the educational use of computers. This is particularly true when special student-oriented programing languages are used. Ten to thirty student hours spent in learning programing enable a student to use computers profitably in course work. This contrasts strikingly with the time needed to acquire a useful knowledge of mathematics or of a foreign language; it is more comparable to the time spent in learning to drive a car. It is the universal experience of all those with whom we have talked that students spontaneously made use of computers in solving problems or handling data even when this was not intended. A further evidence that learning to program is easy is that in many places programing training is extending down into secondary education.

Of course, when time permits, it is desirable to introduce computer use as part of a comprehensive basic course which includes more than just the elements of programing. In many colleges this is a one-semester introductory course with about 3 class hours per week. Such a course typically includes some elementary numerical analysis, a discussion of computer organization, an exposition of algorithms, and an introduction to several programing languages. But there is often effective use of computing without such a course.

The Nature of Educational Computer Use

The earliest educational use of computers provided instruction in programing followed by student use in solving assigned course-work problems adapted to computer solution. This procedure has been in effect for a number of years at the University of Michigan, at the Carnegie Institute of Technology, at Washington University, and a number of other universities, particularly in engineering. Examples of specific problems which are now being used by some of these schools may be found among the examples in Appendix J.

Continued familiarity with the computer allows students to use it in courses in which no such use is specifically required—reducing data obtained in laboratory courses, or making statistical evaluations in sociology courses, for instance. Familiarity of faculty as well as students with computing leads to the assignment of computer-oriented special problems, and even to undergraduate student research projects which could not be carried out without computing. Such student work is valuable education and highly desirable.

It has been proposed that computers be used for "computer-assisted instruction" in which the student interacts with the computer during a learning period. It is clear that much of this will involve more than passively following a previously prepared routine; it will involve data analysis and data presentation. Whether or not computer-assisted instruction using a computer becomes widely used is an educational and economic problem. Surely, however, the cost of trying it to find how it works is a legitimate educational expense.

It is of the utmost importance to keep in mind that computing should not be thought of primarily as a new subject to be taught in addition to all the other important material now in the curriculum. Teachers who make use of computers in a wide variety of subjects have found that their material can be taught more rapidly, more thoroughly, and more meaningfully with the aid of computers. The examples given in Appendix J include comments by the instructors which specify why solving these problems with the aid of a computer has particular educational value.

We Have Second Class Education for the Majority

Adequate computing is not available today in many fine small colleges. Further, even in many larger colleges or universities which have reasonably powerful computers, the computers are not accessible to the majority of undergraduates, either through lack of an appreciation of the usefulness of computing on the part of the faculty, or lack of suitable instruction, or lack of suitable computer languages, or through the way in which facilities are administered or financed. Yet these institutions train undergraduates of excellent ability. Many of these graduates will go out into the business world where they will need to understand and use computers. As evidence for this fact, in 1965 about $2.4 billion were spent for new computers and it is estimated that the salaries of the programers and operators and associated overhead costs for installed machines more than equaled that amount. Consequently, the total expenditure for computers was more than $5 billion in 1965. These figures are even more impressive when we consider the rapid growth of computing (summarized in App. I). The freshman enrolling in 1966 will be employed in 1970 in a world using more than twice the computing capacity now available.

Many others of these undergraduates will go on to a wide variety of graduate work unequipped with a simple but vital skill in problem solving, and unaware of its power and versatility. The handicap of a lack of understanding and skill in the use of computers is extremely severe in all areas in which data analysis is vital, in learning as well as in practice—in business, in the socal sciences, in psychology, in geology, in the health sciences, for example. In a very real sense, students who have not learned to use computers are badly equipped for the postbaccalaureate world.

Based on the estimates for all university computer expenditures (research and education) contained in the Rosser report,* less than $25 million was spent on *educational use of computers* in 1965. Because of the large variety of computers and the uncertainties as to actual costs, it is difficult to interpret this figure. However, if all of this money had been spent for computing service from the largest and most efficient university centers (for example, using an IBM 7094 II at a cost of $300 per hour of processing), about 1 minute of computing was available per undergraduate for the entire year. Put another way, about 5 percent of the students could have received adequate computing service (about 20 minutes of processing for the year). In practice, this money undoubtedly was not used this effectively since it was necessarily distributed very unevenly.

We believe that undergraduate college education without adequate computing is deficient education, just as undergraduate education without adequate library facilities would be deficient education. At present, deficiency in computing is widespread. We believe it to be vital to the national interest as well as to the welfare of the individual student to remedy this deficiency quickly. How can the deficiency be remedied and what will the remedy cost?

What Is Adequate Service?

What is adequate college computing service today, in 1966? Several things are essential even to the most modest user if the aim is education rather than hard knocks:

1. *Adequate instruction in and consultation concerning computing.* Besides a good introductory course, the student should have available adequate supplementary material, and someone available to help him when he has trouble. It is desirable that the operating system be kept up to date, but any changes in the system must be documented and users given help in adapting.

2. *Adequate software.*** The writing of programs should be made as simple as possible. Failure to run should lead to good diagnostics. Various languages, and facilities for adding new languages, should run as a part of the operating system without delays or changes in operation.

3. *Reliable operation.* Interruptions are bound to occur because of equipment failure, and there will be occasional interruptions because of hardware or software changes. However, if students and faculty are expected to use

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*"Digital Computer Needs in Universities and Colleges," publication 1233, National Academy of Sciences.

**Apps. B, C, and E introduce some of the jargon, e.g., hardware, software and, turn-around time, commonly used by computer specialists.

computers routinely, operation of a center must not be interrupted significantly by computer science experiments, unusual scientific or accounting jobs, or when examination time takes away those students who help to run the center. As far as is physically possible, the computing center should be open to users on a regular schedule.

4. *A fast turn-around time.* Instantaneous response is an ideal. Overnight delay is hardly tolerable. A delay greater than overnight is not acceptable for most purposes.

This is what can be called adequate in 1966. Other desirable things are available now and will be essential before 1971. These include:

a. *Interactive remote consoles.* Those who have used them in undergraduate education are convinced that interactive consoles are superior to batch-processing operation. When using these consoles the student types a program and special commands to the computer and then receives a response from the computer while still seated at the typewriter. The response either points out errors or inconsistencies in the program or presents the results of the requested computation. This reduces the time required to prepare a correct program and provides immediate reinforcement to his learning process.

b. *Graphic output.* In many cases, graphs or scatter diagrams or drawings are more desirable than tabular printouts as output. Present equipment can produce such plots on 35 mm. microfilm negatives cheaply, quickly, and without laborious programing. The negatives can be used in a reader or large prints can be made if desired.

c. *Visual displays.* The immediate presentation of graphic data on a cathode-ray tube is an extremely powerful tool in teaching a large variety of subjects. It is used currently in many applications.

d. *New forms of input.* Many new applications or modes of operation require special input devices such as the following. (1) Direct connections allow data to be transmitted directly from experimental apparatus rather than by reading meters and typing the values into the computer. (2) A character recognition scanning device makes some typed or printed material available as input without requiring laborious keypunching. (3) A "light pen" combined with a cathode-ray tube allows one to give directions to the computer by pointing at a selected portion of a display and allows one to draw input graphs.

Who Should Use Computers?

We have outlined features of good computing service which are now available, and indicated others which will be available soon, to a small percentage of students at a few colleges. What portion of the undergraduate enrollment has immediate need for such service?

This question was approached by classifying the needs of major curriculum divisions as substantial, limited, or casual. In the first category (which includes all engineering students, for example), an introductory course in the freshman year would allow the students to make routine use of the computer in many courses throughout their undergraduate career. Students in the second category (many business students, for example) will probably take an introductory programing course at an early stage of their education and then make some use of the computer in three or four other courses during their 4 years as an undergraduate. Students in the third category—such as English majors—may not make any use of the computer as part of their major study, although it is quite likely that even they will be exposed to it and find it useful in a few courses.

By sometime in the 1970's it is doubtful that more than a few percent of the students will graduate without having made some use of computers. A rough guess of the portion of the undergraduate enrollment in each of these categories as of about 1972 is tabulated in appendix I and suggests that approximately 35 percent will make substantial use, 40 percent will make limited use, and 25 percent will make casual use.

Problems To Be Overcome

If good quality service is to be made available on a large scale there are four primary problems which need to be faced: First, how are the required funds to be obtained? Second, how can the necessary facilities be provided? Third, what faculty education is necessary? Fourth, how can the costs be controlled?

Problems of Paying for Computing Service

It is reasonable to ask why the use of computers and the implementation of computer techniques in undergraduate education is singled out in this report for such extensive Federal support. Our colleges and universities clearly have a central responsibility to pioneer in and to adopt new educational techniques and methods. What is so special, then, about the use of computers in education?

The answer lies in the extremely rapid growth rates in computer-related costs which are being experienced by many universities (and should be experienced by more of them). Universities and colleges, whether public or private, are all faced with rising costs and a precarious balance between income and outgo; the public institutions are overwhelmed by the tidal wave of student enrollment, whereas the private institutions are struggling to provide improved student services and to keep pace with rising faculty salaries in an enterprise dependent upon relatively fixed income sources.

Many of our institutions of higher learning have already responded to the significance of computers for all aspects of their programs by establishing new departments of computer sciences. Such a step is a major one for any university, involving new long-range commitments to faculty tenure and to providing building space. Yet, in addition to these very substantial financial loads, the universities also face the very high cost of hardware and manpower to generate and use software. And these total costs are mounting at incredible annual growth rates—figures as high as 45 percent per year are given in the Rosser report—which are an order of magnitude larger than the budgetary growths universities are used to providing from their own funds, with *great* effort, to academic divisions.

Rightly or wrongly, the long range commitments and relatively fixed income components of American institutions of higher learning simply do not allow rapid turnoff of existing programs nor rapid generation of substantial new non-Federal sources of income. The colleges and universities face an explosively advancing technology in a technique which very likely will have revolutionary implications for undergradate education and for the Nation—with institutional financial resources which may permit response at only one-tenth of the rate adequate for keeping pace with the developments.

The sources of computers and of funds for computers and computing service at universities and colleges have been various and confusing. For example, IBM supplies machines and service free and shares operating costs at the Western Data Processing Center at UCLA. IBM uses half of the computer time and the other half is used without charge by UCLA and over 100 other participating institutions. The latter pay only for either wire transmission costs if terminal facilities are on their campuses, or for the mailing of programs and data. The equipment and operating costs of computing at the Irvine campus of the University of California are at present a part of the educational budget. At one college visited, a wealthy benefactor had recently given money for a computer which was hurriedly chosen and purchased without adequate advice or consultation with the faculty. The computer had inadequate hardware and software and no adequate provision was made for its operation, but due consideration was given to the benefactor's dislike for paying rent.

Great good has been done through donated computers, obsolescent computers, huge educational discounts, grants for the purchase of computers, and the struggles of enthusiastic men with inadequate machines. However, computers that are both free and useful will in the future be available to very few users. Further, the operating costs of a computing center are substantial and easy to underestimate. Computers become obsolescent in a few years, so that money spent in buying a computer provides for only one generation of students. Computing is rather a continuing expense than a capital investment. Obtaining computing is not like buying a building, it is like paying, year in and year out, for light or water.

In seeking efficient and effective computing, a school should choose wisely among various options. (1) It can purchase service from a commercial service center. (2) It can obtain service from a university service organization such as the Western Data Processing Center at UCLA. This requires only card punches and a printer, or perhaps consoles, on its own campus. (3) It can run one or more of its own computing centers which are generally accessible to users. (4) It can provide various departments with computers for limited or restricted use.

The last is almost certainly the most costly, for it tends to lead to low usage or to careless, noncompetitive and unevaluated usage; in one guise or another it calls for a greater total number of maintenance, operating, and programing consulting personnel, and it makes it hard to keep software and hardware up to date. Further, the rental cost per unit operation will be higher.

To the unwary, the third alternative can easily seem to be more economical than paying for computing service. It is easy to forget the inevitable cost of expanding, replacing, and updating both hardware and software. It is easy to underestimate the cost of computer time used in updating the center and making it serve with high efficiency various different needs, old and new, including the running of undergraduate educational programs and the running of powerful research programs. It is easy to underestimate the cost and the difficulty of obtaining and holding personnel who are adequate to keep the center current.

With all these alternatives available, it is very desirable to allow a school to choose that one which best suits its needs and circumstances. Consequently, we strongly recommend that the Government agencies which support computing allow the schools to be free to apply the funds either to the purchase or rental of equipment and the support of staff, or to the purchase of service.

Estimation of Cost of Adequate Computing for Undergraduate Education

Universities get computing at bargain rates compared with industry. Either there is no charge for space, or the charge is much lower than in industry. Reasonably skilled student help is available at as low as $1.25 an hour, and salaries for professional help appear to be lower than in industry. Educational discounts have reduced machine costs. Certainly, those who pay for campus computing get it at a bargain rate.

Even though educational computing seemingly comes at bargain prices, adequate computing can be a backbreaking burden for an institution which has no place for it in an already tight budget. We find that some of the most advanced institutions with the best computer services are the hardest pressed for funds. Those who are least hard pressed for computing funds are those which have no computing to trouble their budgets. These institutions which stand most in need of computing will have the greatest difficulty in finding funds for it. We do not believe that adequate educational computing can be established throughout American higher education in the near future without some new source of funds. It is, of course, important that colleges demonstrate conviction and earnestness by bearing what burden they can—in manpower and enthusiasm as well as in dollars. But to succeed they will need financial help.

In Appendix G we estimate the cost of providing in all our colleges and universities educational computing at a level of a relatively advanced school in 1965–66; e.g., Dartmouth. Costs per student per year depend on the field of study, and range from perhaps zero to at least as much as $120 per year. The estimated total cost averages approximately $60 per student per year. To meet this goal by 1972, the cost for all colleges would rise from $100 million per year in 1968–69 to $414 million per year in 1971–72.

Although this is a small fraction of the total yearly cost of student education in colleges and universities (about $9 billion* in 1971–72), it is still a large cost. But it is not large compared with the costs of many other facilities which are deemed essential. Let us, for instance, compare the average cost of $60 per student per year with some other costs.

Perhaps the most direct comparison can be made with the library. A sampling of college and university libraries indicated that operating costs range between $50 and $200 per student per year. According to the 1965 Digest of Educational Statistics (table 81) the average current fund expenditure for libraries in 1963–64 was about $48 per student. This is probably an underestimate of the real costs since it is unlikely that it properly allows for donations and depreciation. Thus, the computing expenditure being considered is roughly comparable to that for a minimal library.

Another comparison can be made with the cost of a laboratory used for specialized training. A freshman chemistry laboratory, for example, is estimated to cost $95 per year per *chemistry student* taking this laboratory course. This includes the depreciation for building and equipment, cost of expendables, salaries for laboratory staff, but not faculty salaries.

The average total cost per student per year is difficult to determine from the accounts kept by most universities. However, it has been estimated to range from a low of $900 at some small liberal arts colleges to more than $4,500 at the best technical schools. From the Digest of Educational Statistics (table 81) the current-fund expenditure for all institutions in 1963–64 for educational expenses was $5.5 billion. The total plant value was $17 billion and if we estimate depreciation and interest at the low value of 5 percent, total educational expense was $6.3 billion or $1,250 per student. Thus, the computing expenditure we are considering is about 4 percent of present annual cost.

We wish to make it clear that the figures cited above, though they may seem large, represent only the money needed for all our schools to get where some are now. However, the facilities on which the calculations are based are able to meet the needs of very advanced computer users for either research or educational purposes. This will open the way to even more imaginative and computationally demanding educational use of these systems. Such experimentation should be encouraged wherever possible even though it may require additional expenditures.

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*This does not include organized research or expenditures for auxiliary enterprises or student aid.

Providing the Funds

Several government agencies have been supporting the growth of computing in colleges and universities. The NSF, ARPA, NIH, and AEC have all recognized the needs even though they could provide only modest support and that mainly for research. We are now urging large scale support of computing for educational purposes. Several government agencies have been supporting the growth of computing in colleges and universities. We do not wish to make detailed recommendations as to which agencies should provide this support and how they should implement a program. However, it seems desirable that the Office of Education should be much more active than it has been. For this reason, we recommend that the Office of Education, in cooperation with other government agencies, actively encourage colleges to provide adequate computing through sharing of the cost. Such governmental cost sharing should include special grants to cover transient costs when service is being initiated or larger facilities are being installed. It is particularly important that the Government be prepared to provide a large fraction of the annual costs of this service. Such support should be planned and administered on a long term basis.

Problems of Providing Facilities

We believe that even if money were available, adequate educational (or research) computer centers could not be staffed in all the colleges and universities that need them in the next 5 years. There are simply not enough able, experienced people available to the colleges to do this.

It would be practical, however, by enlarging and modernizing well-run university computing centers to give adequate remote service to a considerable number of other colleges and universities in their geographic areas. If the distance between the center and the school served is not excessive, communication costs would be tolerable. Such expansion and modernization of centers would have an additional benefit in providing experienced universities with improved facilities for their own computer science education and research. In some cases it will be necessary to set up new centers (run by groups of colleges organized for this purpose or by private companies) to provide this service.

Large computing centers can provide high quality remote service while using a batch—processing type of operation. The system in use at Case Institute of Technology furnishes a particularly good example of this. However, present experience tends to show that immediate access to computers through interactive remote consoles will be practical and desirable, rather than a luxury. It is a conclusion, rather than a recommendation, that a large part of the necessary computing service will be provided by systems of this sort.

Extensive use of large computing centers providing remote service to several schools should alleviate the staffing problems and help reduce costs, but it does lead to some other problems. First, although there is some experience with the management of such joint centers, much more will be needed. In Appendix G it is suggested that many such cooperative arrangements can be initiated immediately using standard batch-processing systems in order to provide experience as rapidly as possible. Second, different schools have differing characteristics and it is not easy to achieve the necessary cooperation among the participating schools. It is important that the computing service be designed to meet the needs of all the schools insofar as possible. Third, the transmission costs can be excessive if suitable facilities and tariffs are not provided (App. H contains a brief discussion of some of the difficulties). However, aggressive action on the part of the universities, the Government, and appropriate industry can overcome these difficulties.

Many of the larger schools will need the entire capacity of one or more of the largest computers available to provide for their own research and educational usage. However, wherever possible, it is desirable that these schools also supply computing service to smaller nearby schools. In a few cases this may even justify and require the use of more than one large computer at a center. We recommend that universities and the Government cooperate in the immediate establishment of large central educational computing facilities located and equipped so as to be capable of serving several institutions. In particular, it would be desirable that the funding procedure encourage the development of such centers. Provision should be made for supporting the centers while usage builds up, or in the face of temporary fluctuations in usage.

In making the cost estimates cited above, it was assumed that service would be provided from (in 1971–72) hundreds of advanced computer centers, using the best new-generation machines provided with remote consoles. We are convinced that this is an economical way of supplying service. It was for this reason that we made this assumption as a means for estimating total cost. While we expect that much of the service will be provided from such centers, we do not intend to specify any single means for supplying service. Some day it may be possible (though this seems to us very unlikely) for one computer to serve all of the Nation's users, but that is not yet. Some day it may be possible to obtain the best grade of service from a small computer on each campus without problems of operation, maintenance, or obsolescence, but that day is not yet. Today, it takes several large machines, which may use remote consoles as well as batch processing, to serve the various needs of a very large university, while one machine can serve the needs of a smaller university or of a number of colleges. Certainly, colleges will not obtain educational computing in a completely uniform and entirely predictable way.

It seems desirable and likely that in many, if not most, cases educational computing will be supplied from university centers which are also used for research and perhaps for administrative computing. In some cases small colleges may be so remote from existing or new centers that they may have to establish and use limited computer facilities of their own. Finally, as we have noted, some needs for educational computing may be met through centers established by groups of universities, or through private services.

Problems of Educating Faculty

Obviously, the faculty plays an important role in determining the rate at which computing is introduced into undergraduate courses. We feel that an intensive effort will be required to show the faculty the advantages and importance of computing and to help them to learn to use computers effectively. A number of suggestions to this end are contained in Appendix D.

There are basically two types of faculty education required if educational computing is to find a useful place in a college. First, the campus must have at least one faculty member who can teach a good basic programing course. This faculty member can be in any department—his prime attribute can be enthusiasm. Many young faculty members are already reasonably well qualified to teach such courses; others will need to participate in summer institutes or other special programs.

The second type of faculty education which is needed is more difficult to provide but is not unfamiliar. It is the basic education associated with any substantial revision of course material. To take maximum advantage of the computer it is frequently necessary to integrate new problems into a reorganized course. Planning problems and preparing the course revision require a large amount of time and effort from the faculty members involved and a consequent reduction of available teaching staff. Once done, of course, the normal amount of effort required from faculty members to keep abreast of a field is sufficient to make such courses generally useful by all members of the department. The examples in Appendix J illustrate the results of this kind of problem planning at several schools. The final report on "The Use of Computers in Engineering Education" * contains a list of 66 problems for various engineering fields. The rate at which problem planning and course revisions can be carried out depends heavily on faculty interest and on their understanding of the power of the computer as well as on the availability of facilities.

Because of the great importance of this faculty education, we recommend an expanded faculty program of education to provide adequate faculty competence in the use of computing in various disciplines. The Government should provide all funds necessary to support such a program.

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*"The Use of Computers in Engineering Education," final report of project supported by the Ford Foundation, College of Engineering, the University of Michigan, Ann Arbor, Mich., Jan. 1, 1963.

The Problem of Controlling Computing

It has often been proposed that computing should be an overhead item—that it should be supplied to students and faculty without any formal procedure of allocation, as is library service. We believe this to be unrealistic.

It is perfectly possible for one user to write one program which justifiably (although more often unjustifiably) will run one or more days on the most advanced computer available. Such a monopolization or preemption of a university library never occurs and thus does not pose a comparable problem.

Although most computer runs are short (less than a minute), to arbitrarily limit the time any program can run would preclude some important and legitimate uses of computers. Further, in the absence of adequate control, students can fritter valuable time away in meaningless computer use even when the running time is short. Therefore, control cannot be exercised by just limiting the maximum length of any run, but instead requires that cumulative use records be maintained for each user. We find that institutions which have a well-run computer center keep careful records of computer costs, and keep careful records of computer usage by assigning job numbers and charging computer time against jobs. This accounting will be more complex but no less essential for remote consoles.

Some universities (Michigan, for example) allocate computer usage among various departments on the basis of time. Others (Harvard, for example) allocate computer usage on the basis of dollars. We believe that measurement in dollars is more meaningful to users and is more useful in comparing the value of computing with the value of, say, laboratory apparatus or special-purpose computers than is measurement in terms of computer time. Regardless of whether the unit is time or money, it is important that some allocation procedure be used which provides effective control.

Measurement of computer usage in dollars need impose no extra burden on faculty members, and might indeed eliminate the burden of arranging or begging "free" computer time here and there, as some faculty members must do at present. For example, faculty members can have budgets (the source may be university department funds, contract or grant funds) from which their students' computer costs for basic instruction, course problems, or research work can be supplied.

Keeping just account of costs of computing can be a powerful tool in university and agency hands in avoiding unprofitable research programs. The cost of extremely lengthy computations in various fields, including medicine, information retrieval, and artificial intelligence, should at all times be clear to the research worker, the university administration, and the funding agency. This does not mean that a uniform accounting system should be imposed on universities, but merely that the accounting system used by each university should be clear and should apply to all computing services.

We recommend that colleges and universities develop and use accounting procedures which accurately measure the cost and utilization of computer services. With such information, the allocation of computer time for research and education and the anticipation of associated costs should be made on a realistic and measurable basis. This should encourage a more balanced allocation of funds for research and educational uses.

III. THE COMPUTER SCIENCE STUDENT

We have noted in the introductory section of this report and in Appendices A and I the magnitude and rate of growth of computing in this country and the need for more men trained in computer science.

Computer science advances and changes as rapidly as all of the computer art. Thus, it would be futile as well as highly undesirable for us to try to describe or prescribe in detail what computer science is or should become. That is a matter best left in the hands of the academic community, to evolve through interaction with the computer industry and users of computing, academic, and nonacademic.

Computer science had its academic origins in designing and building computers in universities. Indeed, the very first electronic digital computer, the Eniac, was built at the Moore School of Electrical Engineering at the University of Pennsylvania. Today, it is no longer appropriate for a university to build a large-scale machine to provide its routine computing service. We also believe that the time is rapidly passing when it is appropriate for every university to develop a large-scale system program for its routine computing center. These aspects of hardware and software will be largely the province of commercial enterprises because the great effort involved in such developments cannot be carried out without excessive delay in the universities.

Yet men must be educated to understand hardware and software very deeply. By providing such education, the universities cannot only supply the computer industry with needed expert manpower; they can strongly influence progress in both hardware and software. Progress requires both university research and commercial enterprise. In general, universities will work on special hardware and software necessary to exploit computers in new ways for new or more efficient uses. This will include the design and construction or adaptation of special peripheral equipment, the development of the necessary software, the devising of new program languages, and the derivations of special procedures or algorithms for obtaining desired results.

Education for such research in computer science includes theoretical studies of machines and machine organization, the study of software and languages and their relations to a wide variety of disciplines, the study of hardware, and appropriate background work in mathematics, physics, and other fields of engineering and science.

This work calls for access to and interaction with a good computer center.

Since many computer science departments also grant a master's degree, it is difficult to separate the undergraduate use from use at the master's level. Graduate work in computer science calls for substantial use of computer time in carrying out research on software and toward new computer applications. Such time may often more appropriately be paid for out of research project funds rather than as an educational expense.

The demand for people trained in computer sciences exceeds the supply. In fact, we have noted previously that one argument for supplying educational computing remotely from centers which serve many schools is that there is not enough trained manpower to establish and staff good computer centers in all colleges. In trying to evaluate the needs, we have been unable to find adequate data on the number of men with various skills now employed in the computer field in industry, government, and schools, or any meaningful estimate of the number who will be needed in the future. (What seem to be the best estimates available are given in App. I.)

We strongly recommend that the Federal Government collect meaningful data concerning computers and the jobs, personnel, and educational facilities associated with them, and endeavor to make useful annual forecasts. We caution that because of the rapid evolution of the computer art and its highly technical nature, useful studies must rely on well-informed and astute knowledge of the state and evolution of the art as well as on statistics.

Despite the importance of instruction in computer sciences, the total amount of computing connected with such instruction will certainly be small compared with the total amount of undergraduate educational computing which we have estimated earlier in this report because there are so many fewer computer science students than there are college undergraduates. Thus, *if the deficit in undergraduate computing is made up,* as we propose, an adequate amount of computing would be available for computer science education. It is of course important that such use be recognized as a part of the educational use of computing.

We must not, however, overlook the quality of computer facilities necessary for good education in computer sciences. In order to provide the computer experts who are needed to produce the new computers and computing techniques which are so vital to our national defense, to increasing our productivity, and to improving our standard of living, we must have excellent computer science departments at a number of schools. Though computer science education and research need place only modest demands on a large computing center, the quality of the center is of utmost importance.

It is hard to see how a master's program in computer sciences can be conducted without use of a center of such quality that costs would be about $1 million a year. Of course, most of the yearly cost of the center would be covered by charges for uses other than computer science education. For first-rate doctoral work, a center at the forefront of the art is desirable. We estimate the annual cost of operating such a center to be around $3 million. This, for instance, is the yearly expenditure of Project MAC at MIT.

We recommend that the Government expand its support of research and education in computer sciences. Such support should encourage the development of "centers of excellence" in computer science.

IV. INTERACTION BETWEEN RESEARCH AND EDUCATIONAL USES OF COMPUTERS

This report is addressed primarily to the use of computers in education. Nonetheless, we have clearly expressed our belief that the best and most efficient computing is most likely to be obtained from large computing centers with the most modern equipment. These centers can provide for educational uses, but they can also be used for all kinds of research.

It seems very desirable to favor large, up-to-date university centers which can serve a variety of needs, including research and administration as well as education. This is particularly desirable in that the educational load may be more seasonal than the research load, so that a system serving educational needs alone might be nearly idle in the summer. Though the funding of research and administrative computing costs may well be different from the funding of educational costs, it is only reasonable to ask that educational needs as well as research needs be taken into account in establishing and operating large computing centers.

Government accounting practices have made it very difficult for colleges and universities to utilize fully that Federal and private support for computers or computer service intended for unsponsored research and education (as distinguished from research paid for by grants and contracts). Treatment of a grant for educational use of a computer as a reduction in total cost reduces the hourly charge for computer time paid by *all* users and has the effect of shifting research costs to educational users. The DOD has recognized this, and now has an agreement with the National Science Foundation not to treat NSF educational grants for operating expenses as a reduction in sponsored research costs.

We recommend that the present DOD–NSF agreement be extended to other Government agencies and private supporters and include both capital and operating cost grants.

There is another way in which research computing may seriously affect the educational use of computers. We believe that unless computers used in research are managed wisely and effectively, money which might be used to advantage in education may be wasted.

We have observed that most colleges and universities have no adequate provisions in their budgets for educational computing. For research computing, funds are often available through project grants from various Government agencies. Yet even here the Westheimer report* shows that in the field of chemical research, in 1963, of $4.2 million value of computation, only $0.56 million, or 13 percent, was paid for under research contracts, while in 1964, of $6.4 million only $0.72 million, or 11 percent, was paid for out of contracts. The difference represents "manufacturers discounts, grants made to computer centers by the Government, and hidden support of chemical research from the universities themselves."

The Westheimer report anticipates a very rapid growth in computing in connection with chemical research, just as a rapid rise in all research computing is to be expected. Unless adequate provisions are made for the support of research computing, the very resources which are needed for educational computing, and indeed, for the rest of education, may be drained away by unforeseen research needs.

Thus, it is extremely important that in planning for support of research, Government agencies plan for adequate support of necessary computing. It is equally important that universities keep adequate account of the cost of computing and allocate computing services, measured in either time or dollars, so as to provide for their educational needs. It is particularly important that universities do not carelessly allow overruns in research computing to penalize the education of their students.

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*"Chemistry: Opportunities and Needs," National Academy of Sciences, Washington, D.C., 1965.

V. THE COMPUTER AND SECONDARY EDUCATION

Training in the use of computing and in the nature of computers and computing is rapidly but randomly invading secondary education. We have felt it impossible to approach the problem of computers and secondary education quantitatively both because of the sheer magnitude of the problem and because of the lack of quantitative information. However, through personal experience and the testimony of others we have formed some preliminary opinions concerning the problems involved.

The advantages of introducing the use of computing into course work and of teaching something about the nature of computers and computing in secondary schools can be considerable, either as a preparation for college work, as a preparation for semiprofessional or vocational training, or as a preparation for employment. Such training in secondary schools will increase rather than decrease the amount of educational computing required in colleges and universities.

There can, however, be real disadavantages to an unwise introduction of computer training in high schools. Detailed and narrow training in commercial programing languages and the operation of commercial computers has apparently led some able young people to accept dead end jobs in a market hungry for people with computer knowhow, when they might better have gone on to college and fitted themselves for more productive and rewarding places in our economy.

Vocational training in computers and computing has a legitimate place in terminal secondary education, but this may not be the chief contribution which computing has to make to secondary education. Secondary-school students should be taught what computers and computing are. In addition, it may be that computers can be used to improve the teaching of many courses. Computers may be useful in stimulating the interest of students who cannot be reached in other ways.

Computing is best used in secondary schools by means of convenient facilities, such as remote consoles, and simple instructional programing languages. Instruction in the nature of computers and computing can be by means of special texts supplemented with specially designed experimental equipment.*

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*Such as the material in the text, "The Man Made World," and the associated experiments being prepared by the Engineering Concepts Curriculum project under the auspices of the Commission on Engineering Education.

Unfortunately, this approach is contrary to much that is now being done in secondary education. Sometimes the computer used is one which is used for administrative purposes, which may be ill adapted to proper introductory instruction. Sometimes the computer used is a small machine purchased or rented primarily for instruction, but awkward to use and of limited computing power compared with a remote console attached to a large modern machine—or even compared to job shop operation by courier or mail on some accessible more powerful machine.

This is not to deny that good and useful secondary-school instruction can be carried out with less than optimal facilities. But we believe that money is often spent, and financial obligations incurred (through the purchase of computers which will be expensive to replace when they become obsolescent and expensive to maintain at all times) which could be better applied in securing service from a more suitable source. Indeed, many secondary schools may, for want of guidance, reexperience all the difficulties that universities and colleges have already gone through in coping with computers and computing.

As to financing computing in secondary education, there is some evidence that some communities and school boards have been liberal in financing computers and computing in secondary schools. Thus, the lack in many cases may be one of guidance rather than of funds. This will not, of course, be true in remote or underprivileged areas.

We urge that the Office of Education and the NSF jointly establish a group which is competent to investigate the use of computers in secondary schools and to give schools access to past and present experience. Cooperation between secondary schools and universities, and particularly providing service to secondary schools from university centers, should be encouraged.

Computers and computing are already invading junior high schools and elementary schools, and this same recommendation should be applied to junior high school and elementary education.

APPENDIX A

COMPUTERS IN HIGHER EDUCATION

Introduction

In attempting to assess the educational need for computers in colleges and universities, we find ourselves compelled to believe that within a decade essentially all university and college students will require some basic understanding of digital computation. We believe this will require all institutions offering collegiate level instruction to have on campus sufficient input-output facilities to permit students to prepare problems for digital computation and to receive results; the actual computer may, in many cases, be remotely located. Every such institution will also require, on its staff, enough faculty with computer experience to teach computer use and provide computer experience in the various disciplines.

In short, we believe that the computer and computing are rapidly coming to have an impact on the life of practically every member of our society. Most people educated beyond the high school level will have occasion to make use of these tools, and all will need sufficient understanding of their possibilities and limitations realistically to appraise the new opportunities now available for information processing.

While many of the arguments which compel us to believe in the desirability of very widespread acquaintanceship with computers are spelled out in the Rosser report, we wish to emphasize a few key points.

The rapidly increasing use of digital computers in this country is documented in Appendix I. A $2.5 billion industry with a 25 percent per year growth rate in capacity and a similar growth rate in people to develop and operate the computers is significant in itself, especially since the numbers do not include the large number of military or special purpose industrial computers now in use.

In all parts of education, government, or industry, digital computer use has come about because it is an effective tool. Each new use leads to several more—like bookkeeping, inventory control, airlines reservations, on-line control of manufacturing processes, design of structures, diagnosis of disease, market analysis and forecasting, design and analysis of experiments in the social and natural sciences. It is a new tool with unusual implications.

Suddenly, it seems, the computer and its many applications has opened a new technical field to women. Of all technological fields the computer area shows the greatest growth in the employment of women, largely those with baccalaureate degrees in mathematics. And the large growth in mathematics degrees is a major factor in the total increase in science and technology baccalaureates in recent years. At a time when technical "manpower" is in ever shorter supply, the almost 50 percent addition possible through the use of "womanpower" is a boon indeed. It is a boon both for the numbers available and for the breaking down of traditional attitudes which discouraged women from entering technical fields.

In national defense computers are the unique ingredient. No airplane can fly without one; no missile guided or defended against. Effective materiel procurement requires them. Transport of supplies by ship or rail is planned by them. Space exploration could not be done without them. Nuclear reactors require them. But every use demands people who are at home in the computer world. People must have understanding of computers which varies from that of the highly specialized Ph. D. designer to the crucial technician maintainer and operator. Now to mechanical know-how most Americans must add computer know-how. We need to encourage the same love affair with the computer that we now have with the automobile.

In every day life the computer problem looms equally large. Automation is the usual name for the problem. It means using computers to control machines and processes previously carried out by human labor. A threat perhaps, but equally an opportunity. Many people can be relieved from jobs of mental or physical drudgery. With additional training they can carry out more complex jobs using computers than their abilities allowed before. How many checkout clerks in supermarkets could add well enough to hold their jobs without a computer—the cash register?

Clearly some acquaintance with digital computers will be as essential to the next generation as is now familiarity with the automobile and the radio. It will need to know what a computer is, its uses and limitations. For college and university students the time required to get such familiarity may be about that to learn to drive a car. Unfortunately, parents can't teach about computers so the colleges and universities must.

An Estimate of Needs

A quantitative *estimate* was made by classifying the needs of major areas of study as (1) substantial, (2) limited, and (3) casual. Category 1 includes primarily all the biological and physical sciences and engineering and roughly half the social sciences, mathematics, and business and commerce. Category 2 contains the other half of mathematics, social science, and business plus three-quarters of education. Category 3 includes mostly the humanities.

In category 1 an introductory course in the freshman year would allow students to make routine use of the computer in many courses—probably more than 50 percent—throughout their undergraduate career. Students in category 2 will probably take an introductory programing course at an early stage of their education and then make some use of the computer in three or four other courses during their 4 years as an undergraduate. Students in category 3 need not make any use of the computer as part of their major study although it is quite likely that even they will find it useful in a few courses. By sometime in the 1970's it is doubtful that more than a few percent of the students will graduate without having made some use of computers.

A rough guess of what percent of the undergraduate enrollment will be in each of these categories as of about 1972 is based on 1963–64 data given in figure 1. Assuming that the *relative* enrollments in these major areas of study will not change substantially from these figures, about 35 percent of the students will be making substantial use, about 40 percent limited use, and 25 percent only casual use of computers in their undergraduate education.

A common characteristic of both the general and professional education in computers is that the student is gaining understanding of and facility with a tool. Such instruction is often best given, in terms of motivation and of drill, in connection with the study of the discipline for which the tool is important. Thus we would expect that students of education might learn digital computation in connection with analysis of educational statistics. Introductory physics students might find digital computation a powerful tool for reduction of experimental data or in simulation of experiments.

Institutions will differ in the way in which they introduce students to digital data processing, and this is healthy. But if the most is to be made of limited time—and every new subject introduced into the college curriculum now faces rigorous competition from other subjects which can make excellent claims on the student's time—it is important that computers be used to extend rather than displace the student's grasp of other subject matter. The problems listed in Appendix J, and the faculty comments on their use, indicate that this principle is already understood and applied on campuses now making the most use of computers.

In undergraduate education the computer offers especially exciting possibilities in teaching the formation of hypotheses or theories. Physics, for example, has been very successful in describing and explaining the physical world because theories could be constructed and results calculated on the basis of fundamental principles. Yet it still is sometimes hard to separate the logical from the empirical content of our knowledge of physics.

As Prof. W. M. Huggins of Johns Hopkins University has pointed out, computer methods now permit us much more readily to examine the logical consequences of a given set of assumptions in nearly any discipline without turning to analogous systems in the real world which imperfectly realize the assumptions. In these situations, the implications of theory may be examined with a "pure" system in which a prescribed sequence of operations can be performed precisely as specified without any uncertainties or irrelevancies from the real world contaminating the investigation.

This manmade world of the computer will enable all disciplines to a greater or less degree to generate an idea, hypothesis, or theory, and test its value completely independent of its practical realization. Added to this possibility is the computer's ability to handle data with all the complexity that exists in the real world. Such powers have never existed so extensively before and have tremendous potential at all levels of the educational process.

An Important Plus

We have discussed the need for and cost of education in the use of computers as a tool in solving problems in various disciplines. This seems to us the most direct route to knowledgeable use of computers by students and faculty. But the presence of a computer, or its input-output terminals, on a campus creates an additional opportunity with equally great rewards.

These rewards could come in the form of assistance in the teaching-learning process itself. Many exciting new experiments have the student interacting directly with the computer through typewriter, visual, or audio presentations. With competent and careful programing of the computer, one finds it helping the student to construct answers rather than picking them from a list; to learn as he would from a teacher.

The potential rewards to the student and increased effectiveness of the teachers merit intensive development of computer assisted learning at all educational levels. With large computers, more faculty experienced in their use, and better input-output devices, this teaching process can be explored and developed toward the end of the period we are considering. It is possible that productivity gains will provide much better education at very reasonable costs.

The Educational Value of Computing

Obviously, it is not possible to establish definitely the value of computers in the educational process. Not only is there inadequate experience as yet, but the entire educational process involves many intangibles. It is possible, however, to compare the estimated cost of $60 per student per academic year with the costs of some other educational facilities to allow a judgment as to whether the balance is reasonable. A sampling of college and university libraries indicated that operating costs range between $50 and $200 per student per year. According to the "1965 Digest of Educational Statistics" (table 81) the average current fund expenditure for libraries in 1963–64 was about $48 per student. This is probably an underestimate of the real costs since it is unlikely that it properly allows for donations and depreciation. Thus, the computing expenditure being considered is roughly comparable to that for a minimal college or university library.

Another comparison can be made with the cost of a laboratory used for specialized training. A freshman chemistry laboratory, for example, is estimated to cost $95 per year per ***chemistry student*** taking this laboratory course. This is the marginal cost of this course; i.e., it includes the depreciation for building and equipment, cost of expendables, salaries for laboratory staff, but not faculty salaries nor general university overhead expenses.

The average total educational cost per student per year is difficult to determine from the accounts kept by most universities. However, it has been estimated to range from a low of $900 at small liberal arts colleges to more than $4,500 at the best technical schools. From the "Digest of Educational Statistics" (table 81) the current-fund expenditure for all institutions of higher education in 1963–64 for educational expenses was $5.5 billion. The total plant value was $17 billion and if we estimate depreciation and interest at the low value of 5 percent, total educational expense was at least $6.3 billion, or $1,250 per student. Mr. Harold Howe, U.S. Commissioner of Education, has stated (*New York Times,* Mar. 27, 1966) that costs to un-

FIGURE 1.—*Classification of Computing Needs by Major Areas of Study*

[Based on bachelor's degrees conferred in 1963–64]

Major area of study	USAGE		
	Substantial	Limited	Casual
Agriculture			4,600
Architecture		600	
Biology	23,000		
Business and commerce	28,000	28,000	
Education		84,000	28,000
Engineering	33,000		
English and journalism			35,000
Fine and applied arts			16,000
Foreign language and literature			12,000
Forestry		1,300	
Geography		1,200	
Health	1,000	10,500	
Home economics			5,000
Library science	500		
Mathematics	9,500	9,000	
Military	2,500		
Philosophy			4,700
Physical sciences	17,500		
Psychology	7,000	6,500	
Religion			3,600
Social sciences	38,000	38,000	
Others			12,000
Total (460,000)	160,000	179,000	120,900
100 (Percent)	35	40	25

dergraduates in public institutions now average $1,560 a year and in private colleges the present annual average is $2,370. Thus, the computing expenditure we are considering is about 4 percent of present annual cost.

Finally, a collective assessment of the value of computing to the national economy and welfare is represented by the expenditure of business and government for acquiring and using computers. Appendix I shows the historical trend—for comparison purposes, in 1965 about $2.4 billion was spent for new machines. It is estimated that the salaries and related overhead of the programers and operators for existing computers more than equaled that amount. Consequently, total expenditure was more than $5 billion in 1965. Thus, the educational expenditure estimated for 1971–72 is less than 8 percent of all *1965* computing expenditures. The growth rate pictured in Appendix I guarantees that the educational expenditure will be much less than 8 percent of the actual computing expenditure in 1971–72.

What we are saying, then, is that university and college administrators must recognize education in computers as a pressing need and opportunity. It is an opportunity that can be grasped successfully for about a 4 percent increase in their operating budget. This is no mean feat in times of rising costs in all other areas of their operation. But a 1 percent rise might be possible if the other 3 percent came from Federal support. Certainly such a joint effort is essential if computer education appropriate for this country is to come about.

APPENDIX B

SOME FACTS OF LIFE ABOUT COMPUTERS

The mode of using computers has changed steadily through the years. In the earliest days of computers, each user took his program individually to the machine and used the computer either until his problem was solved, or until he ran out of assigned time. This is no longer feasible except in the use of obsolete computers which have been replaced but not discarded, and when one considers maintenance and space for such machines, it is of dubious merit. One can learn something about hardware and diagnostics by maintaining a computer, but one learns nothing about computer usage by having the computer physically accessible.

One of the first advances in adapting computers to easy use was the *open shop* together with *batch processing.* Open shop operation means that anyone who follows specified rules can get a program run, not just a selected group of programers. By batch processing we mean that the programs and data for a lot of jobs which various people want done are put on a magnetic tape and run through the computer in sequence. This means that all programs to be run must conform to certain rules, and use the input and output facilities which are provided for all. All these functions are implemented by a small amount of additional hardware and a large *executive* or *system* program to manage the operation automatically.* Batch processing can cut down the *turnaround time,* the time between handing a job in at a computer center and getting an answer back, to one or two hours.** As computers have come to be used by more and more people for a greater variety of jobs, even this may be too long to wait for an answer.

A recent development which makes computers more efficient and more flexible in use is called *multiprograming.* The flexibility is obtained by having the computer take up tasks in order of their ease or brevity. This is similar to a garage mechanic's having a 5-hour job but taking on easier 5- or 10-minute jobs as they come in. By interrupting the larger job periodically, more customers are satisfied and no one must wait for a very long time. In multiprograming the computer can leave a long job partly done to take on other, shorter ones, then return. This procedure also leads to greater efficiency. Without multiprograming, the entire expensive computer system can be held idle if processing is delayed for any reason; for example, if a new input tape must be mounted during the course of computation. This wastes both time and money, and computer time can be worth as much as a thousand dollars an hour. With multiprograming, another job, or part of a job, can be started (or even completed) during these necessary interruptions.

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*Programs of this kind become an integral part of the computer to users, and so are often called "software" as a contrast with the hardware. The other computer operating schemes mentioned in the remainder of this appendix are also implemented by a hardware-software system, not by hardware alone.

**By use of a special system at the Case Institute of Technology, turnaround time for simple student problems has been reduced to 5 minutes or less.

With multiprograming it is possible to use in one computer many controls and many arithmetic units. This is called *multiprocessing* and permits several jobs to be done simultaneously.

Another recent improvement in computer organization permits many users to have access to the machine simultaneously. This is called *multiple access.* Instead of having one line of jobs coming in one door, there are many doors with jobs coming into whichever doors are most convenient. The computer now cannot stand by one door, but must look all around. Thus there are many input terminals. For instance, at Dartmouth and in Project MAC at MIT, a number of computer users have keyboards by means of which they can call on one central computer.

When there is multiple access to a computer, the computer must decide which input to attend to. This depends not only on what the computer decides is efficient, but on the requirements of the inputs themselves. In some cases, for example, those involving data transmission from distant cities, the information must be handled when it is received. In other instances semiautomatic readout of information (as from satellites) must be handled periodically in order to avoid storage overload, but the computer is more or less free to choose the time. In yet other cases, high-volume inputs such as punched card readers must be serviced very frequently in order to avoid pileup.

It is possible to have multiprograming without multiple access, but providing multiple access efficiently requires multiprograming as well. Most computers do not yet have multiple access, but the newest generation of large machines is well adapted to multiple access. Both multiprograming and multiple access permit increased efficiency of computing facilities and produce better service for more users. We do not yet know what the increase in efficiency will be.

Another rapidly changing feature of computer usage is in input and output equipment. In analyzing data, computers must be able to accept input in forms other than magnetic tape. In some cases they must be able to pick up readings from measuring instruments. In processing photographs of the tracks in bubble chambers or photomicrographs of human chromosomes, computers must be equipped with something like a television pickup device. Using this, the computer must be able to pick up data from different parts of the picture at different times, parts chosen on the basis of what the computer has already found in the picture.

Modern computers have also been equipped with special output devices which can draw pictures as well as with special input devices which can read data from pictures. By programing a computer to draw a sequence of pictures, each differing a little from the previous one, a computer can be made to produce animated movies.

Sometimes it is desirable to obtain a diagram from a computer output without taking a picture and waiting for the picture to be developed. This can be done by storing the output numbers from the central computer in the memory of a small auxiliary computer. The auxiliary computer can then draw pictures on a cathode-ray tube (which is like a TV picture tube), pictures specified by the numbers stored in its memory.

The interaction between man and machine is an essential element in many modern uses of computers. The computer types out a text, or draws a picture, or places packages for minimum wire length, or calculates the deflections in a mechanical structure, and a man observes the result and makes alterations to correct defects or to improve performance. Multiprograming, multiaccess, and peripheral computers and visual displays are important elements in making such interactions between man and machine quick, easy, and efficient.

APPENDIX C

COMPUTER LANGUAGES

Any computer is built to respond to a repertory of instructions which cause the machine to perform arithmetical, logical, and input and output operations. These instructions, which are built into the computer, are called the *machine language* of the computer. The machine language of the computer may consist of two or three hundred (or even more) instructions or *words*.

The machine language of early computers was simpler though less powerful than that of present computers. And all programing was done in machine language.

Today, the majority of people who use computers do not use or know machine language. They write programs in some symbolic, simplified language which is adapted to the problem they wish to solve. The computer is then used to *compile* a machine language program, which is then run on the computer. The computer operates under a complicated *systems program* which controls the programs used to translate from symbolic, user-oriented languages into machine language, provides diagnostic printouts when a program fails to compile, and makes it easy to handle input and output.

The best known symbolic language is FORTRAN (formula translation) which is adapted to numerical computation. FORTRAN is unnecessarily complicated for student use. Several special simple languages have been developed for student use, including MAD (University of Michigan), BASIC (Dartmouth), and CORC (Cornell). These are easy to learn. Perhaps even more important, they take less compiling time, and hence cut down on computation costs.

A large computer with a good operating system will handle programs in many special-purpose languages: languages to simulate economics or machines, languages to do algebraic manipulations, languages to design bridges and electrical networks, languages to produce musical sounds and motion pictures.

The provision of appropriate, adequate, and efficient languages is one of the most vital ingredients in the wider and more effective use of computers. This is a strong reason in favor of providing students and faculty with access to a large and powerful computer, rather than a small computer of limited flexibility and capability.

Appendix D

EDUCATING THE FACULTY IN USE OF THE COMPUTER

This appendix focuses on training the faculty in computer methods. If the rapidly expanded use of the computer creates financial problems for the colleges and universities, so does it pose a problem for faculty members most of whom were educated prior to the present computer revolution. How can they become adequately conversant with computer methods, and how much effort does it involve?

The greatest initial effort to aid faculty members should probably be for disciplines which are already making substantial use of the computer. Engineering comes to mind immediately as an outstanding example. Statistics is another good example of an important computer application; it touches many areas of the social sciences, biological sciences, and physical sciences. It is probable that many faculty members may have their first occasion to consider use of the computer in connection with statistical problems.

Younger faculty, who are closer to their graduate student days, may have greater awareness of the growing importance of the computer, and they may, therefore, be among the first to bring pressure on the computation center staff to learn about the computer. But it has been pointed out that a relatively short interval of intense training can prepare a faculty member to make effective use of the computer, and it is clear that many faculty members from all age groups will—and should—want to become conversant with the computer.

Need to solve a particular set of problems or to keep current in one's field provides an important motivation for a faculty member to seek instruction in use of the computer. This instruction should be followed by self-teaching and learning by doing. Another motivation for the faculty member is his desire to keep pace with his students who have found the computer fascinating and useful. These motivations are present to varying degrees for most faculty members, and the proper response of the institution is to make it as easy as possible for faculty to respond to the urge to learn more about computers. Such learning cannot nor should not be forced.

Here the role of the administration is in providing opportunities. It can also be helpful if, as new faculty are recruited to various departments, individuals knowledgeable in computer techniques are added. These men can be extremely helpful to their departmental colleagues.

Instruction at no monetary cost to the faculty should be offered in a variety of ways; for example, short courses during the academic year, seminars between regular semesters or quarters, and longer courses during part of the summer. Some of the courses should be so general that a faculty member from any discipline can attend and gain something from the discussion. Others should be discipline-oriented and present special techniques that have been advanced to solve particular problems.

It is very important for the faculty to recognize that the time needed to cross a significant threshold of understanding so that one may begin to do useful work for oneself and his students is very low compared to a discipline such as mathematics or operations research or languages. *A 1-week laboratory-oriented course of instruction on computing will enable a motivated faculty member to solve some problems in his own field and provide for him a basic knowledge from which he can advance on his own.*

There is evidence, from experience at schools such as Dartmouth, that a nearby console and simple programing languages, if available, make it especially easy for a faculty member to learn and to experiment with the new tool in spare moments and in private. But whether or not this especially ideal arrangement for learning is present, the statement empasized in the preceding paragraph is valid.

For faculty members who have been contemplating that one of these days they ought to get around to learning something about using computers, the advice is simply: start now. Nearly every college and university computing center has knowledgeable individuals who are delighted to help their faculty colleagues discover this powerful new tool.

APPENDIX E

THE LARGE UNIVERSITY COMPUTATIONAL FACILITY

The Pattern of the Past

In the past, computation has usually come to colleges and universities through a proliferation of computers around the campus, each computer assuming a single role such as teaching, research, or university administrative data processing. While this "solves" the problem of administering computers, albeit in a costly and redundant manner, it generally begs the question of how the computation might best serve the needs of education, and it establishes artificial boundaries which tend to stifle the healthy growth of university computer use.

Not long ago computational devices and the data processing devices were different. Each had a different set of operations and different mode of operation. This made several installations about the campus not only desirable but necessary. The so-called third generation of data processing devices has tended to join the two divergent path trends.

The Place of the Computer in the University

The advent of time sharing, terminals of many types, and the modular computer makes computation more flexible and powerful, but it makes the administration of computation more difficult. In the past a computer has often been administered by some special group which uses it the most, has the money to support it, has the space to house it, or sometimes merely has had the courage and energy needed to obtain the device. While all of these reasons were probably valid at the time the computer was obtained, the passage of time and changing conditions will almost certainly invalidate the original reason for control of the computational facility by a single department or specialized group.

The one thing certain about computing devices of today is that their uses will continue to evolve rapidly. Through such evolution the use of the device spreads through all departments of the university, and will probably become heaviest in data processing rather than in numerical computation.

In order to permit the use of the computers to transcend the normal boundaries of the various university disciplines it is prudent to establish a facility to serve all and sundry areas of the university.

A proper global view by its management enables the computation facility to react to the combined needs of the whole university rather than just the particular needs of a single department or group.

The ultimate administration of the facility should rest in the hands of an administrator so placed as to be cognizant of the total needs of the university. Due to the leadtime necessary to obtain additional or replacement computational equipment, the administrator of the computational facility must be aware of the long- and short-range plans of the university in order to have time to react to planned changes.

It is essential that the management of the facility have sufficient independence so as not to be dominated by any one division of the university and that there be enough intellectual leadership in the center so that it can understand the educational goals of the administration and be competent to work with the faculty and students. Caution should be exercised to make certain that all users have a forum in which their needs and dissatisfactions can be heard. When communication ceases, the usefulness of the facility decreases. This is particularly vital in the field of computer sciences. The computer sciences faculty should not be burdened with the administration of a computer center. Nor should their research and teaching interfere with the continuous and effective operation of the center in providing service. However, computer science people should have a strong voice in the introduction of new hardware and software and in adapting computers to new uses.

Facility Orientation

The chief reason for existence of a computation facility is to provide computation, whether for teaching, or research ranging from history to computer sciences. As long as the facility operates with this goal in mind it should prosper and will probably grow. If, by design or accident, the primary goal of the facility changes from service to some other pursuit, there is a high probability that the facility will falter and probably fail.

In view of the large dollar value associated with computer devices and staffs, it would seem reasonable that all campus computational facilities should be coordinated through one person having the responsibility for the total computational and data processing needs of the campus. If this needed coordination is not provided, it is possible that computational facilities will spring up in several areas and attempt to provide overlapping services. The costs of data processing are high enough at best without further increases due to inefficient management.

The most critical need in university computation is that of a long-range plan. Since the average life of a computer is on the order of 3 years, and the time between order and delivery of the device is on the order of 2 years, it is readily evident that a 5-year plan is the minimum tolerable. In order to plan 5 years ahead, we must peer over the computer designer's shoulder in order to see far enough ahead to have the needed lead time.

Since the universities are training the men of the future, it seems obvious that the men should be trained on the most modern equipment available today in order to have a fair chance in the world of tomorrow.

In view of the proliferation of computer languages and dialects it might behoove the university community to sort through these languages and begin to select the ones which should live and prosper, and through teaching and use attempt to standardize a very chaotic situation.

Facility Operation

In order that the facility provide adequate quality service, it must be user directed. While one computer can work in practically all areas of problem solving, it is rather doubtful that one person can work in all areas. This situation requires that problem-oriented people serve as an interface between the user and the computer. Many of these problem-oriented people will be administratively outside of the facility; some may be within it. The number of interface people will vary widely with the number of user areas served by the facility and the extent of experience and capability of the interface personnel.

In general, the staff of the facility will fall into four categories: (1) administrative, (2) operational, (3) software oriented, (4) user oriented.

The administrative personnel should concern themselves with the long- and short-range plans of the facility while continually cordinating the efforts of the other three groups.

The operational personnel should be concerned with the daily operation of the facility and should attempt to maximize through-put and minimize turnaround time.

The software-oriented personnel should concern themselves with the operating systems of the facility, ever conscious of the needs of both the user and the operations staff. The availability of good software is probably more important than good hardware. It is not necessary or desirable for most schools to write large operating system programs since they will be available from other sources. However, it is important that software-oriented personnel be available to interpret, modify, update, and add to these programs.

The user-oriented personnel are the outward face of the computer facility. They should serve as the buffer and interpreter between the user and the facility. A failure in the first line of defense can well make the rest of the facility ineffectual.

The proliferation of terminals will cause the staff of the facility to be more widely dispersed. The operational staff will have to stay with the computer hardware but the remainder of the staff can go wherever communication lines permit. In general, the user-oriented personnel will follow the terminals. In most cases this will be a short distance from the computer, but in others it could be to other campuses some distance away. As this move occurs it will become necessary to frequently return these people to the mother house for upgrading and rejuvenation.

The Machine

If we accept the premise that all computing gravitates to the largest possible machine, small machine proliferation becomes untenable. While this does not preclude the use of small special-purpose devices for special tasks, it does seem to preclude the need for each user group to have its own machine and appropriate staff.

An unfortunately common first step into the computing field is the acquisition of one or more small machines with complete open-shop operation. While this type operation is rewarding to the user, it is somewhat difficult to justify on a cost basis, and the user soon becomes disillusioned by the limited size and speed of the machine.

At this point most of the users are willing to forego some of the freedom of small machine operation in order to acquire size and speed. The next step is the acquisition of a large high-speed machine to be operated in the batch processing mode. In most instances the small machines remain.

Thus begins the migration from machine to larger machine, in an effort to get the computing capability needed.

Each machine change leads to an anguished period of problem restatement, reprograming, and reorientation. Each machine change brings glee to some and pain to others. One cannot start with the small system and go to the large system without major upheavals or major discontinuities.

The third generation of modular computers with their building-block design and complete upward compatability may make future increases in computing capacity less painful.

If we can assume that the present concepts of a modular computer are to be in vogue for a reasonable length of time, then a progressive plan with incremental steps can be outlined in such a way as to reduce the alternate feast and famine of computational capability brought about by the discrete computers of the past generations.

The advent of the time sharing systems with the provisions for terminals, shared memories, shared peripherals, shared processors, and teleprocessing, should permit the university to lease or purchase just the amount of computing needed and be able to react quickly to changing requirements.

When the terminal is mentioned, one normally visualizes a typewriterlike device with someone operating the keyboard at a poor typing rate. The term terminal should be taken to mean any input-output device available. One can visualize not only typewriterlike terminals in using areas, but also high-speed readers and printers, graphical display devices, and small peripheral computers which store data and process it to some extent but call on the central computer for difficult processing and computation. Such terminals, and problem-oriented languages and compilers open a whole vista of possibilities for university computation utilizing a central processor and time sharing.

Appendix F

WHAT COMPUTER FACILITIES ARE APPROPRIATE

The Larger College or University

A college or university large enough to utilize the computational capacity of a typical computer system would probably decide to operate such a system within its own walls. In the past, this has been supported by a combination of manufacturers' discounts, a Federal grant (usually from the NSF), and funds from the university itself. In some cases complex arrangements with manufacturers have been worked out so that the institution itself bears a relatively small portion of the total cost. In most institutions, the presence of Federal grant money for related projects is used, and in some cases actually sought, to offset part of the operating expense. The extent to which this additional support is available will vary widely, but it cannot be expected in the future to be used to offset costs of educating students. Furthermore, it would be difficult for many predominantly teaching institutions to attract the amount of research funds needed to make any sort of dent. Thus, it would appear that the methods by which colleges and universities have equipped themselves with computers cannot be counted on to supply future educational needs on a broad scale.

Smaller Colleges

There are two ways in which smaller colleges can begin to provide computing power for educational needs. The first is through the acquisition of a "small" computer, such as has been done quite often in the past with the help of matching grants from the NSF Undergraduate Instructional Equipment Branch. This has, in the past, been an effective means for introducing computing to a large number of small colleges, those that were able to present a convincing argument to the National Science Foundation. The small computers provide a good mechanism for the training of a corresponding small number of students, many of whom have been in the past headed for further training in computer science. However, the inability of a small computer to present a truly sophisticated software system for the user will prevent this method from becoming an important vehicle for mass training and indoctrination in elementary programing and principles of computing. Further, the financial burden of this course is high. Manufacturers' discounts have been lowered, and the housing of a computer may pose significant financial hardships on many colleges.

Smaller Colleges

Perhaps the most sensible way for small colleges, and many larger institutions, to provide educational computing service to their students is to obtain one or more teletypewriters or similar consoles connected to a very large and very sophisticated computer system through telephone or telegraph lines. This approach has several advantages. First, the amount of computing power to be supplied to a given school can be easily tailored to the amount of funds that are available. Second, the institution does not have to assume the task of administering, and sometimes developing, a large-scale computer system. Third, every student has the advantage of being able to call on the most sophisticated software systems, something that most institutions could simply not supply on their own.

Actual experience has shown that a single teletypewriter can expose computing to hundreds of students during the course of an academic year. Naturally, a deeper involvement in computers with more frequent exercises will require additional teletypewriters.

One small college has actually used this method to get started in computing. Harpur College in Binghamton, N.Y., has been connected to the Dartmouth Time-Sharing system for almost a year. They plan to obtain their own large computer, but would also be quite happy to hook into a "New York Educational Data System Network."

The ability of a time-shared computer system to provide computing power flexibly, quickly, and in a wide range of quanta, permits a wide variety of administrative structures for providing this service. Large schools, of course, can have their own private computer system. They would be able to experiment with various aspects of computer science and should do so. Components of a state university system could expect to obtain whatever specific computing they needed by tapping into a statewide network.

Secondary Schools

The argument for obtaining service from a time-shared computer system is even stronger in the case of secondary schools than it is in the case of small colleges.

In general, the purpose of secondary-school education in the use of computation should be to enable the student to understand the nature, ease, and power of computation, and to use it in course work in a variety of subjects. This is best done through the use of simplified languages which are not available on small computers.

Any instruction in the nature and organization of computers is best done through special laboratory equipment and experiments, not through operating a computer designed to perform useful calculations.

Teaching technical skills in standard programing languages and in computer operation may indeed divert very able and enthusiastic students from an academic career. Such skills, which now have a ready market, may well be rendered obsolete by future rapid developments in hardware and software. However, such training is necessary now, but it is not appropriate as a part of a college preparatory secondary education.

APPENDIX G

ESTIMATION OF REQUIRED COMPUTER CAPACITY AND COST

Introduction

Estimating the required computer capacity and its cost is difficult because of the complex interrelationship of the needs, the variety of available facilities, and the uncertainty in the possible rate of growth. All of these factors are complicated by the fact that large time-sharing systems for which we have limited experience will be widely available during this period. On the basis of available data and experience we believe that the simple programing languages, convenient terminals, and rapid access of time-sharing systems will lead to a faster growth rate and a more widespread use than with older batch-processing systems. For example, at Dartmouth, within 2 years after installing a time-sharing system, usage grew from essentially zero to the point where more than one-half of the students used the computer each quarter. Further time-sharing systems appear to be an economical means of providing high quality computing service to almost all schools. Purchasing such service is particularly attractive to the large number of schools which do not now have well-trained computer center managers.

Consequently, even though many schools may find it feasible and as economical to use another approach; e.g., a very good batch-processing system such as the one at Case Institute of Technology, we decided to base our estimates on the capacity and cost of computing provided by large time-shared centers. We believe that the costs arrived at in this way are close to those for any other efficient and effective means for supplying service; the use of less efficient computers could, of course, lead either to higher cost or inadequate service.

Estimation of Needed Capacity

The basic unit in the calculation was chosen to be the average number of hours each student is at a console in each week. This figure was estimated as one-half hour per student per week . (Very roughly, this would be equivalent to one-half minute of processing per week on a large batch-processing computer.) It was obtained by estimating that those students making substantial use of the computer would total 130 hours at a console during their 4 years, those making limited use would total 46 hours, and those making casual use would total 18 hours. The average use during a 4-year curriculum, based on the estimated classification according to major areas of study, is then $0.35(130)+0.4(46)+0.25(18)=69$ hours. This is 17.25 hours per year or about one-half hour per week of the school year. The total hours of use in each category might be made up as follows:

Substantial	Hours	Limited	Hours	Casual	Hours
Introductory course..........	10	Introductory course.........	10		
10 other courses, 12 problems per course.......	120	4 other courses, 6 problems per course......	36	3 courses, 3 problems per course......	18
Total.........	130	Total........	46	Total........	18

Many commercial computer manufacturers will be able to deliver suitable time-sharing systems in the interval from 1968 to 1972. To be specific, approximate calculations were made based on approximate costs of two similar systems soon to be available—the IBM 360–67 and the GE 645. As nearly as can be determined at this time, one of these (dual-processor) systems should be able to service approximately 150 active consoles for this type of use. Although service could be available nearly 24 hours a day, 7 days a week, a practical maximum of 100 hours use per console per week is more reasonable. This means that one such center can provide 150 × 100 = 15,000 console hours per week.

Combining the estimates of use per week and console hours available, one center can serve $15{,}000/\frac{1}{2}=30{,}000$ students. This calculation does not depend on the distribution of the students; i.e., one center is needed for a single 30,000 student university or for 30 colleges each having an enrollment of 1,000. In order to get the total computing capacity needed for any year, the estimated enrollment is divided by 30,000. Thus, in 1971–72 the estimated enrollment of 5.5 million students in baccalaureate degree programs would require the capacity of 183 such centers. Forty additional centers would be needed to provide for a 2-year college enrollment of 1.2 million.

Estimation of Costs

The cost of providing this service includes three components: (1) the cost of operating the center, (2) the cost of the consoles, (3) transmission charges for connecting the consoles to the center.

Cost of Operating Center

This cost component was calculated by using approximate rates for the 645 and 360–67 and reasonable guesses for actual costs at a university of the operating staff, space, and consumables. These latter costs are about the same as those for large batch processing systems now being run at such schools as Michigan, Berkeley, Texas A. & M., etc. No allowance is made for educational discounts since these are uncertain and, in any event, should be considered as outside educational support rather than reduced costs. In order to consider costs on an academic year basis, it is assumed that the computer can be used for research or special summer programs during summer months so that only nine-twelfths of the yearly cost should be charged.* It is possible that some research use could be provided during the academic year in the 68 hours of the week not accounted for by the operation assumed above, but this will depend on time-sharing systems achieving a reliability which is yet to be demonstrated so this possibility is ignored. The cost of the first component is then obtained as follows:

Annual equipment rental	$1,500,000
Annual staff, space, consumables	300,000
Annual total	$1,800,000

Academic year total ¾×$1,800,000=$1,350,000
Cost/student $1,350,000/30,000=$45

The annual equipment rental assumed in this calculation is actually somewhat below the actual cost of a well-balanced configuration which would probably be used in all centers also providing for research work. However, accounting methods will probably take account of the simpler requirements for student programs and therefore reflect a reduced rental reasonably close to that assumed in the calculation. The annual cost for staff, space, and consumables could go as high as $700,000 per year which would add $10 per year per student to the cost. However, many universities seem to be operating at a rate close to that assumed so we shall use that figure.

Cost of the Consoles

To average 150 active consoles and still avoid long queues, and to provide for faulty equipment, it is necessary to have more than 150 consoles available. The number needed depends on the distribution of the students since a rather small excess would suffice in case all 30,000 students were using consoles in one room but 100 percent excess is probably needed in the extreme case of 150 small 200-student groups. Therefore, the number of consoles needed for each center will vary between 150 and 300. A reasonable estimate of their cost is $125/month. Since most students are in schools needing at least 10 consoles, it is assumed that about 25 percent excess is adequate. The cost per student per academic year is then $125 \times 9/200 \times 1.25 \approx \$7$.

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*Special consideration would have to be given those cases in which greatly reduced summer usage would cause financial problems.

Cost of Transmission

The transmission costs are very difficult to estimate since they depend on the geographical distribution of the centers and the students. Our calculation does not really specify the number of centers, let alone their distribution, since it is based on educational use only. It is likely that the number of centers will be at least two to four times greater since the research use will continue to exceed educational use. Three cases might be representative.

1. University—15,000 students, a research load about equal to the educational computing load. In this case the transmission charges are essentially zero since the center could be supported on this one campus and local line charges are negligible.
2. College—1,600 students, 100 miles from computing center. Need an average of 8 active consoles, assumes that 12 will be provided. The 12 transmission channels can be supplied with one Telpak A facility which has 12 terminals.
   Line charges ($15 per mile per month for 12 channels)
      $15×100 miles=$1,500 per month
      $1,500×9 months=$13,500 per academic year
   Terminal charges ($30 per terminal per month)
      $30×12 terminals=$360 per month
      $360×9 months=$3,240 per academic year
   Total charges per academic year=$13,500+$3,240=$16,740
   Cost per student per academic year=$\frac{\$16{,}740}{1{,}600}=\$10$
3. College—400 students, 200 miles from computer center.
   Need an average of 2 active consoles, assume that 4 will be provided.
   Line charges ($2 per mile per month per channel)
      $2×200 miles×4 channels=$1,600 per month
      $1,600×9 months=$14,400 per academic year
   Terminal charges ($24 per terminal per month)
      $24×4 terminals=$96 per month
      $96×9 months=$864 per academic year
   Total charges per academic year=$14,400+$864=$15,264
   Cost per student per academic year=$\frac{\$15{,}264}{400}=\$38$

Considering these calculations as reasonable limits, the cost of transmission can vary between $0 and $38 per student per academic year.

A sampling of the 1964 college enrollment figures shows that about 13 percent of students are enrolled in schools with less than 1,000 total enrollment and about 37 percent are in schools with more than 10,000 total enrollment. We assume that the latter group is typified by the first college, the former by the third college, and the remaining 50 percent by the second college. A rough estimate of the average transmission cost per student per year is then $0.13 \times \$38 + 0.50 \times \$10 + 0.37 \times \$0 = \$10$.

Total Costs

The total of these three components of cost in 1971–72 is summarized in the table below.

Annual support needed in 1971–72

	4-year colleges (in millions)	2-year colleges (in millions)
Enrollment	5. 5	1. 2
Computing, $45/student	$247	$54
Consoles, $7/student	38	8
Transmission, $10/student	55	12
Total	$340	$74

How the Transition Can Take Place

Assuming that adequate support is provided to reach this level by 1971–72, how can the transition take place?

By the 1968–69 academic year, manufacturers will be able to install from 2 to 10 powerful, high-capacity time-sharing systems at universities with a staff able to manage them. In addition, there are likely to be at least another 10 to 20 simpler and smaller systems, such as the one at Dartmouth, in use at universities. However, the bulk of educational computing will still be provided via batch-processing (but multiprogramed) systems. Between 80 and 120 colleges and universities which now have large computing centers (using machines classified in the Rosser report as type A, B, or the larger members of type C) will have increased their capacity by changing over to the larger, faster, and cheaper machines now being installed by many manufacturers.

These installations (in particular the more than 50 schools having centers based on type A or B machines in 1966) will have the facilities and skilled personnel to be able to provide service remotely to several hundred other colleges. This service will be provided via special terminals which provide card punching, printing, and card reading; e.g., the IBM 360/20, UNIVAC 2000, GE 115, or others. Such terminals will make reasonable computing service available to many campuses without requiring large numbers of skilled operational personnel to begin operations. At the same time it speeds the development of the competence of computing center personnel at both ends of the scale. The large centers providing the service will gain experience in the problem of running centralized services; the smaller schools obtaining the service will become familiar with the requirements for providing and using good service.

By the 1969–70 period some 20 to 40 other schools should be capable of managing time-sharing systems and by 1970–71 an additional 40 to 80 will have caught up. Thus, it appears to be possible to develop the competence to manage large centers of this sort at the same rate at which manufacturers will be able to deliver such systems during this period. To maximize the development of this management ability, the larger colleges and universities should be encouraged immediately to increase the size of their computing centers and to use the extra capacity to provide remote (batch-processing) service to other campuses.

Support During the Transition

How much support will be needed during the interim period? In the Rosser report approximately $60 million (including almost half of the computer science use) was projected as the cost of educational computing in calendar year 1968. This projection was based on a 1965 survey and a conservative 20 percent growth rate. If we assume that this is approximately correct for the academic year 1967–68 and apply the conservative 20 percent growth rate used in the Rosser report, $72 million would be the cost for 1968–69 *assuming that no special measures are taken to accelerate the educational use of computing*. This is about 20 percent of the support level that we recommend for 1971–72.

If a special effort is made prior to mid-1968, it should be possible in 1968–69 to take a significant step beyond the growth projected in the Rosser report. One portion of this step would be represented in the additional educational use made of the (between 2 and 10) large time-sharing systems installed by this time. Assuming five such systems installed, the total cost for that academic year would be about $8 million. However, these systems would all be located at schools which now have well-developed computing centers and a portion of this cost, say 75 percent, is already represented in the Rosser report projection. Thus, the additional support represented in these systems is only about $2 million.

Another portion of the step would be represented in the additional remote terminals connected to the larger batch-processing centers that will exist in 1968–69. One of these terminals can be provided for about $40,000 per year ($20,000 for equipment rental and transmission costs, and $20,000 for personnel and space). Providing such service to 200 colleges in this year would increase costs by about $8 million and should make reasonable quality computing service available to an additional million students.

The final portion of the step would be represented in an accelerated growth rate in educational computing use at schools where good computing service is available. By providing funds so that no available facilities must be idle, by supporting faculty training programs so that interest is stimulated, and by using the remote terminals to make service available to more students, the growth in this year could be brought to 50 percent rather than 20 percent. Thus, instead of the growth from $60 million to $72 million projected in the Rosser report, the increase would be from $60 million to $90 million. (This increase includes $6 million of the $8 million costs projected for time-sharing systems.)

Combining all these elements, the total level of expenditures which we believe to be attainable and efficiently usable in 1968–69 would be $100 million. Of this, $8 million might be used for large time-sharing systems, $8 million for remote terminals connected to batch-processing systems, and $84 million for computing centers primarily using batch-processing systems.

In order to achieve the desired level of computing service by 1971–72, a 60 percent growth rate would be necessary. This would imply a support level of $160 million in 1969–70 and $260 million in 1970–71.

APPENDIX H

THE COMMUNICATION PROBLEM

Everything points to an increasing use of powerful central computers connected to remote consoles of a variety of types. When all consoles are on a single campus, the cost of communication between consoles and computers is small. However, it is highly desirable to provide service to colleges and secondary schools which may be tens or even hundreds of miles from the central computer. In this case the cost of data transmission may be a major obstacle to the educational use of computation.

Various suggestions for cheaper communication have been made. In the case of an integrated system—a State university system, for instance—the State university could operate its own private data transmission network, in which case the educational computing power could be transmitted along those lines. This network might consist of long lines or perhaps microwave relay or coaxial cable. Or, a small piece of an educational television circuit could be used. The data requirements for a teletype machine are small and could be handled by a very small band in the TV circuit.

However, the only communication facilities which are immediately available to interconnect all schools, wherever they may be, are common-carrier communication facilities. It seems possible that common-carrier communication could be provided for substantially less money, both through technical improvements in the use of present facilities, and through providing classes of service more appropriate to present and future needs.

There are present service offerings in which the messages for a group of from 10 to 20 teletype consoles are multiplexed electronically for transmission over a single telephone channel. However, these services are not available in all areas as a standard offering. Work toward improving and reducing the charge for such service might prove highly valuable.

The introduction of new service offerings is more difficult, for it requires both action by the common carriers and approval by State regulating bodies and/or the FCC.

Present services are ill adapted to many computer uses, which call for connections longer than is common in telephone calls, but only a fraction of the time provided by a private line.

A determined study seems called for, involving common carriers, and those knowledgeable in the educational use of computers (the Association for Computing Machinery is a possibility), to seek out ways for meeting the needs of American education.

2

APPENDIX I

THE GROWTH OF THE COMPUTER INDUSTRY

The purpose of this section is to describe what is known and has been forecast about the needs for computers and for manpower capable of operating and using computers. At the present time, statistics describing the present situation are fragmented and somewhat untrustworthy. To expect precise forecasts in such a rapidly changing field is obviously ridiculous. Nonetheless, the best predictions that can be made might enable academic institutions to make better plans for the future.

There are a number of reasons why statistics gathering and forecasting are difficult. First, the rapid change of computer types and performance characteristics and peripheral equipment makes even the meaning of the number of computers installed difficult to define. Second, as computers get more efficient, new uses and new capabilities will bring new opportunities in fields and areas which cannot be forecast now. Third, the occupational titles and duties vary markedly from one installation to another, and a particular position may be described by over 100 titles.

Despite all these difficulties, a major effort was made by the American Federation of Information Processing Societies (AFIPS) to examine the literature carefully and to examine some of the data and the problems involved in determining manpower and equipment projections. These data have been made available to the Panel and have been the starting point for the summary information described here.

Number of Computers Installed and Projected

The estimated number of computers installed and projected in the AFIPS report is given in figure 1. The rate of increase over the previous 5-year period is also given. "Large scale" computers are defined for the decade of the sixties as those costing $750,000 or more. For the decade of the fifties, the classification was made on the basis of the speed and storage capacity of the computer. Figure 2 shows the increase graphically.

The AFIPS group does not expect the rate of growth of computers in service to increase as rapidly in the future as it has in the past, partly because the number of computers in service is so large, and partly because the capabilities of computers are increasing so rapidly. It is expected that the total number of computers *and related devices* will triple between 1965 and 1970, but much of the increase includes expansion of input and output equipment and auxiliary consoles.

The critical point in the estimate of the number of computers needed involves the feasibility and practicality of time sharing. Successful time sharing computers might increase the number of large scale computers even more rapidly.

Value of Installed Computers

Another measure of the increase of computing is the dollar value of the computing installed. Although this measure gives some indication of the man-years of effort that have gone into building computers, the technological revolution which has taken place in computer design and construction does not make these figures an accurate estimate of computing capability. Figure 3, taken from the Rosser report, gives an idea of the increase in computer capability as a function of time. These results should be kept in mind when looking at the increases in value and in the number of computers.

Figure 4 shows the cumulative value of installed computers in the world (leaving out special purpose military computers for which the figures are not available). The table also shows the estimated order of use of computers in foreign installations and also shows the rank in descending order of the countries which use computers the most.

It can be seen that at the present time the United States dominates the world market, but that other nations are moving up, both in use and in production.

Cost of Computing

The cost of computing is much more than the cost of the computer and peripheral equipment (so-called "hardware" cost). Additional costs, usually referred to as software costs, result because programs must be developed for the machines. There are also operational costs, of course.

The U.S. Government has computed the cost for its own installations and determined that software cost is approximately equal to the cost of hardware in its normal use of computers.

The figures given in figure 5 are taken from the AFIPS report. Note that there is a decline in the expected cost of hardware (chiefly because the Government has been moving from a generally leasing policy to a purchasing policy for its computers), but that the software costs are increasing.

Estimates on Manpower Supply and Needs in the Field of Digital Computing

The AFIPS study mentions the extraordinary difficulty of trying to determine the actual supply and the projected needs for computer-related manpower. Job descriptions were not standard, there were no data available with regard to the situation before 1960, and the projections were hard to make because of the lack of knowledge of the type of equipment that would be installed.

Nonetheless, an estimate of the supply and needs was made. The results can be summarized as follows:

1. Hardware systems development. This field attracts bachelors, masters, and doctors, to different levels in the industrial hierarchy. Much of the needed development between now and 1970 is expected to take place in peripheral equipment. Although no clear-cut number of people working in this field was determined, the number was expected to more than keep up with the expected supply of engineers and more than double between 1960 and 1970. The Department of Labor estimates that there were 66,000 production workers in the entire industry in 1964.

2. Systems analysts. This type of employee usually has a bachelor's degree, and occasionally a master's. Because of the difficulties in definition, only estimates of the number of people now in the field and the total expected need, can be obtained. The AFIPS report estimates that there were about 10,000 systems analysts in 1960, 60,000 in 1965, and that perhaps 200,000 will be needed in 1970.

3. Programers. There are widely varying estimates for the number of computer programers expected. Much of the difference in the numbers depends on definitions of programers and on the degree of programing which future computers will require. In any event, most programers have a bachelor's degree training. The estimates are that there were 40,000 programers in 1960, about 60,000 in 1965, and between 200,000 and 650,000 needed in 1970. (It seems unlikely to the Panel that the larger number will in fact be needed.)

4. Computer operators. In general, computer operators have a high school training. In 1965 there were about 43,000 operators. In 1970 the need is estimated at about 80,000. Others estimate this number as high as 130,000.

These estimates show that there will continue to be a need, particularly for college graduates, in the computing field. It does not appear that there will be any enormous shortages, except perhaps in the programing area, if the greatest estimate of need is correct. The salaries have gone up in these occupations, but not spectacularly. It is not certain how many of these employees should be trained in universities and how many will get mostly on-the-job training for routine work.

Figure 1.—*Number of digital computer installations in the U.S., actual and estimated, 1950–75*

Year	Total installations	Annual growth rate over previous 5 years	Large scale installations	Annual growth rate
		Percent		*Percent*
1950	10–15	....	4	....
1955	1,000	....	275	....
1960	6,000	43	903	26
1965	30,000	38	2100	16
1970	50,000	11	2500	4
1975	80,000	10	4000	10

Source: AFIPS.

FIGURE 2 NUMBERS OF COMPUTERS IN SERVICE ACTUAL AND ESTIMATED

1950–1975 Source: AFIPS

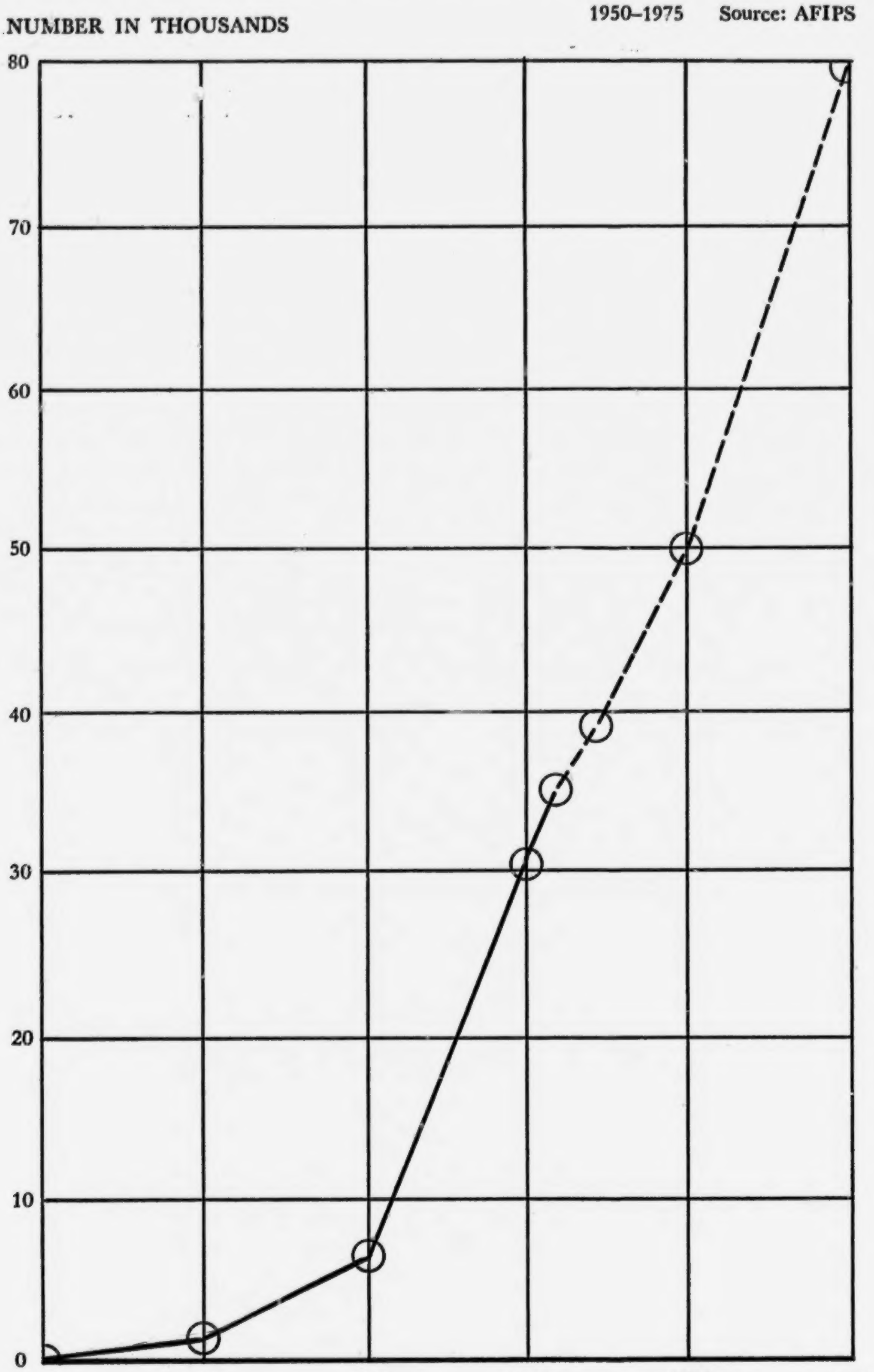

FIGURE 3.—*The decreasing cost of computation*

Means	Technical innovation	Time to do one multiplication	Cost of machine per year	Cost of machine per hour	Cost of 125 million multiplications
Desk calculator...	Mechanical.....	10 secs.....	$800	$0.20	$2,150,000
Harvard Mark I...	Electro-mechanical.	1 sec.......	50,000	12.50	850,000
ENIAC..........	Electronic......	10 ms......	100,000	25.00	12,800
UNIVAC I (type D).	Large memory..	2 ms.......	300,000	50.00	4,300
UNIVAC 1103 (type C).	Magnetic core..	500 μs.....	420,000	70.00	1,420
IBM 7094 (type B).	Modern transistor.	25 μs......	840,000	140.00	132
Stretch (IBM 7030) (type A).	Parallel circuits.	2.5 μs.....	1,920,000	320.00	29

Source: National Academy of Sciences, Rosser report.

FIGURE 4.—*Installed equipment*

[Billion dollar investment in EDP]

Year	1950	1955	1960	1965	1970	1975
United States............	0.030−	0.730+	1.48	7.8 +	18.00+	31.5
Other Countries..........	....	.001	.039	3.000+	6.00+	9.4+

NOTE.—Values given in this table are cumulative values.

Major countries ranked in descending order: (1) England*, (2) France**, (3) Japan, (4) Germany, (5) Italy, (6) Sweden, (7) Netherlands, (8) Canada, (9) U.S.S.R.

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*England currently meeting 54% of its computing needs with indigenous products and trend is upward.

**France produces 16% indigenous computers for its requirements.

Source: AFIPS.

FIGURE 5.—*Table of U.S. Government expenditures for computing*

[Millions of dollars]

	Fiscal year		
	1964	1965	1966
Hardware..................................	$481	$441	$410
Software..................................	$355	$401	$434
Percent of total dollars for software............	42	48	51

NOTE.—1. Hardware cost—Rental plus purchased computers. 2. Software cost—Personnel as reported in ADP inventory of U.S. Government responsible for the operation and development of software in its strict sense.

Source: AFIPS.

APPENDIX J

EXAMPLES OF THE USE OF COMPUTING IN COURSE WORK

A chief point of this report is that at a number of colleges and universities computing has become an integral and indispensable part of course work in a wide variety of subjects. Computing has extended the range of material that students can understand and make use of. This is best illustrated by a few examples drawn from various fields of study and from various institutions. These examples consist of problems, groups of problems, and in one case an undergraduate research project. The examples vary widely from field to field. The computer is a universal tool; the nature of the work is dictated by the field of study. Since there is nothing like a consensus as to "best" examples, this sampling is for purposes of illustration only, and is in no sense intended to represent the best that can be done.

The examples are presented in various degrees of detail. In the case of some examples we have obtained very brief comments from the instructor indicating why he thinks it advantageous to be able to use a computer in solving this problem. Of course, in most cases the significance of the computer is not in the solving of any one problem but in its use for a whole set of problems.

Business

1. B.A. 133, Investment Principles and Policies, School of Business Administration, UCLA.

The students collect data from the financial statements of two companies (different for each student) that are then analyzed by a previously prepared computer program to form the basis of an investment analysis and recommendation.

Instructor's comments: The computer does analysis computations that would take over 100 hours on a desk calculator. Without it, the analysis would be simplified to eliminate many important aspects; with it, more time can be spent on the interpretation and meaning of the analysis.

2. B.A. 140, Elements of Production Management, School of Business Administration, UCLA.

Students program a subroutine decision rule to establish production levels and raw material orders for a manufacturing process with known costs and unknown demand. This subroutine is then used as part of a previously prepared program to simulate the operation of the concern over a period of time.

Instructor's comments: The computer enables students to explore the process with 10–12 cases, each with 10–12 time periods. It takes the exercise out of the realm of arithmetic and makes it a real learning experience in the management of a process. Emphasis is placed upon heuristic decision-making and the dangers of suboptimization.

Biology

Application of computer modeling in biological instruction at the University of California, Irvine.

1. A model of a reproducing population of organisms has been used to illustrate the interaction of natural selection and random drift in one laboratory exercise designed for the beginning biology course. Because of the size of this class (10 laboratories of approximately 24 students each) it was impractical to have the students interact directly with the computer. Therefore, the experiments were set up and run on the computer prior to the time for the laboratories. The data output from the experiments were supplied to the students along with descriptions of the experiments. Then, at the time of the laboratory period, by using multiple-parameter sets and replications of runs on the computer, each student at a given laboratory table could be supplied with a unique data packet. This was done to give the student the impression that he was working with genuine experimental data, as was indeed the case. Judging from remarks made by students, this attempt to create an atmosphere of genuine experimentation was successful.

During the laboratory exercise the student followed suggestions and guidelines provided by the laboratory writeup in analyzing the data. He was asked to graph the results of each experiment performed for him on the computer and compare the results of this experiment with other experiments analyzed by his table partners. He then answered certain questions about the results of the experiment, these questions also being supplied by the laboratory syllabus.

2. A second laboratory exercise based on this same model of evolutionary dynamics was devised for a class in human genetics. The class contains both biology and nonbiology majors. For the purpose of this laboratory period it was divided into two groups of about eight students each. Each group met on separate occasions with the instructor in the computer terminal room. There, as a group they selected for modeling several genetic systems known in humans. With the help of the instructor they chose values for the input parameters necessary for the model. This data was then fed via an IBM 1050 terminal and university-leased telephone lines to an IBM 7094 computer located at the University of California at Los Angeles. Within 2 to 10 minutes the experimental results were returned from the computer and printed out on the printer at the terminal. The students then im-

mediately analyzed their results either graphically or numerically, and made changes in the input parameters if desired for the next run. In this case, obviously there was a much greater opportunity for participation on the part of the students in the experimental design. It is anticipated that in the future this computer/student interaction will be extended from the group to the individual by means of multiple terminals and input/output interpreters with plain language capabilities operating in a true time-sharing mode.

Instructor's comments: Biological concepts from the disciplines of population genetics and population dynamics are particularly hard to illustrate to the student because of the time and cost barriers. The computer is used to overcome these difficulties. It should be pointed out that the language and the concepts involved in these laboratories were biological in nature and not computer oriented. The problem of the experimental design and parameter specification was put in biological terms and the entire exercise was made as real as possible, except for a vast compression of the time scale which is possible only with the aid of a computer.

Mathematics

Numerical analysis courses at Rensselaer Polytechnic Institute.

Two undergraduate courses in numerical analysis require extensive use of the computer. The basic mathematical material is standard work in numerical methods, such as solutions of equations, differential equations, and linear algebra, and there are separate courses at the institute in computer programing and data processing. However, the students are assigned "problems by the bushel" on the computer. In addition, in a successful recent experiment, half the students were required to undertake a major project of preparing a program for a pretty complicated big problem. The total enrollment in these courses is about 700 students and the IBM 360/50 system is used roughly 6 hours a day, 5 days a week for homework.

Instructor's comments: George Handelman, chairman of the Mathematics Department at RPI, expressed himself roughly as follows about the introduction of the computer into the numerical analysis courses: "It's so fantastic it's almost impossible to say how much better the course is. The amount of practice the students get is up by one to two orders of magnitude."

Engineering

1. CM 341, Rate Processing I, College of Engineering, University of Michigan.

As a problem, students analyze the flow in a pipe network. A network consists of a number of horizontal pipes, of specified diameters and lengths, which are joined at n nodes numbered $i = 1, 2, \ldots, n$. The pressure is specified at some of these nodes. There is at most a single pipe connected directly between any two nodes. The students write a MAD program which will accept information concerning the above and which will proceed to compute (*a*) the pressures at all remaining nodes, and (*b*) the flow rate, and direction of flow in each pipe.

Theory. The flow rate Q_{ij} from node i to node j is related to the corresponding pressures p_i and p_j by

$$|p_i - p_j| = c_{ij} Q_{ij}^2 \tag{1}$$

in which Q_{ij} is plus or minus for flow from i to j or vice versa, respectively. In the following version, Q_{ij} will automatically have the correct sign:

$$Q_{ij} = (p_i - p_j) \sqrt{\frac{1}{c_{ij}|p_i - p_j|}} \tag{2}$$

Here, c_{ij} will depend on D_{ij}, L_{ij}, the diameter and length of the pipe connecting i and j, and also on a friction factor f. At any node where the pressure is not specified, the sum of the flows from neighboring nodes must be zero:

$$\sum_i Q_{ij} = \sum_i (p_i - p_j) \sqrt{\frac{1}{c_{ij}|p_i - p_j|}} = 0 \tag{3}$$

When applied at all "free" nodes, equation (3) yields a system of nonlinear simultaneous equations in the unknown pressures. Such a system can be solved by Newton-Raphson iteration, but the following method is perhaps simpler conceptually. Note that $(p_i - p_j)$ is more sensitive than $(p_i - p_j)^{1/2}$ to variations in p_j. Thus, if an approximation to p_j is known, a new (and hopefully better) estimate p_j^* is suggested from (3) as

$$p_j^* = \frac{\sum_i a_{ij} v_i}{\sum a_{ij}} \tag{4}$$

in

$$a_{ij} = (c_{ij}|p_i - p_j|)^{-1/2} \tag{5}$$

Equation (4) can be applied repeatedly at all nodes until the computed pressures show little further change, or until a preassigned number of iterations has been exceeded. It is understood that the most recently estimated values of p_i will always be used in the right-hand side of equation (4).

Notes

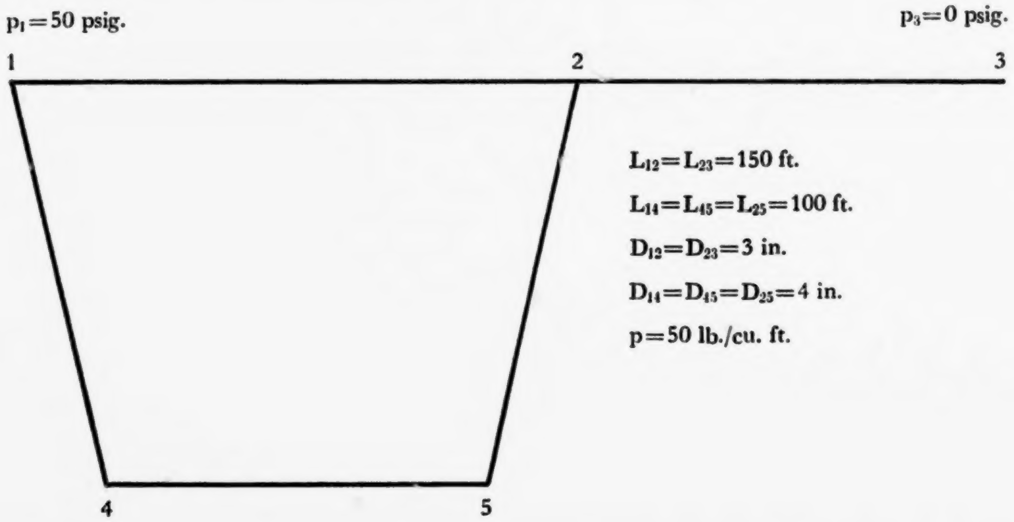
(*a*) Students may collaborate as far as discussing methods of attacking the problem, questions of fact about MAD programing, general principles, etc. However, each student must individually write his own program and prepare a written report.

(*b*) Execution time estimates should be kept to no more than 10 seconds (*10 in columns 52–54 of I.D. card) unless *after* consultation with the instructor there appears to be a definite reason for increasing it.

(*c*) Liberal use of blank spaces between words, variables, operators, etc., and occasional use of remark cards identifying key computational steps will make it *much* easier for the instructor to understand your program.

Data

Your program should solve the following network and also one of your own choice. Assume a Moody friction factor of 0.056.



$L_{12}=L_{23}=150$ ft.

$L_{14}=L_{45}=L_{25}=100$ ft.

$D_{12}=D_{23}=3$ in.

$D_{14}=D_{45}=D_{25}=4$ in.

$p=50$ lb./cu. ft.

Instructor's comments: CM 341 is an undergraduate fluid mechanics and heat transfer course taken during the junior year. Most of the students have previously taken an introductory computer course (Math. 273).

Before a computer was made available to the students a problem of this sort could not be assigned because the calculations would have required too large a portion of their study time. Now they are able to do several such problems which provide a good base for considering more complex and realistic systems later. The students have reacted very enthusiastically to its introduction into the course.

2. Aerospace Engineering 320, College of Engineering, Texas A. & M. University.

A sounding rocket is launched in a vertical direction. It has a burn time of 5 seconds. During this 5 seconds the mass is being reduced. The forces acting on the rocket are thrust, drag, and weight. The thrust varies slightly with altitude; the drag varies as the square of the velocity and slightly with altitude; the mass varies with time. Using the given FORTRAN program, calculate and print out t, y, m, T, D, V and a at time increments of 1 second, starting with $t=0$ and continue through $t=10$ seconds. However, you should calculate values of y using $h=0.01$ second (i.e., $\Delta t=0.01$).

The governing equations are:

$$D.E. \qquad F=\frac{d}{dt}\left(m\,\frac{d}{dt}\right)$$

$$\text{Mass:} \quad m=(7-t)\,\frac{40}{32.2} \text{ for } t=0 \text{ to } 5 \text{ sec.}$$

$$m=\frac{80}{32.2} \text{ for } t=5 \text{ to } \infty$$

$$\text{Force:} \quad F=T-d-m(32.2)$$

$$\text{Thrust:} \quad T=520+0.00005y \text{ for } t+0 \text{ to } 5 \text{ sec.}$$

$$T=0 \qquad \text{for } t>5$$

$$\text{Drag:} \quad D=(1-0.000005y)(2.6\times10^{-3})\left(\frac{dy}{dx}\right)^2$$

Instructor's comments: This problem requires the numerical solution of a basic type of equation and demonstrates the relative ease of solving a problem on the computer that is very difficult to solve otherwise. The realistic problem made possible by the computer relates the material covered in the mathematical treatment of numerical methods to a "real" engineering problem and gives students confidence in their ability to solve real problems.

3. Civil engineering 1.51, Structural Analysis and Design, Civil Engineering Department, M.I.T.

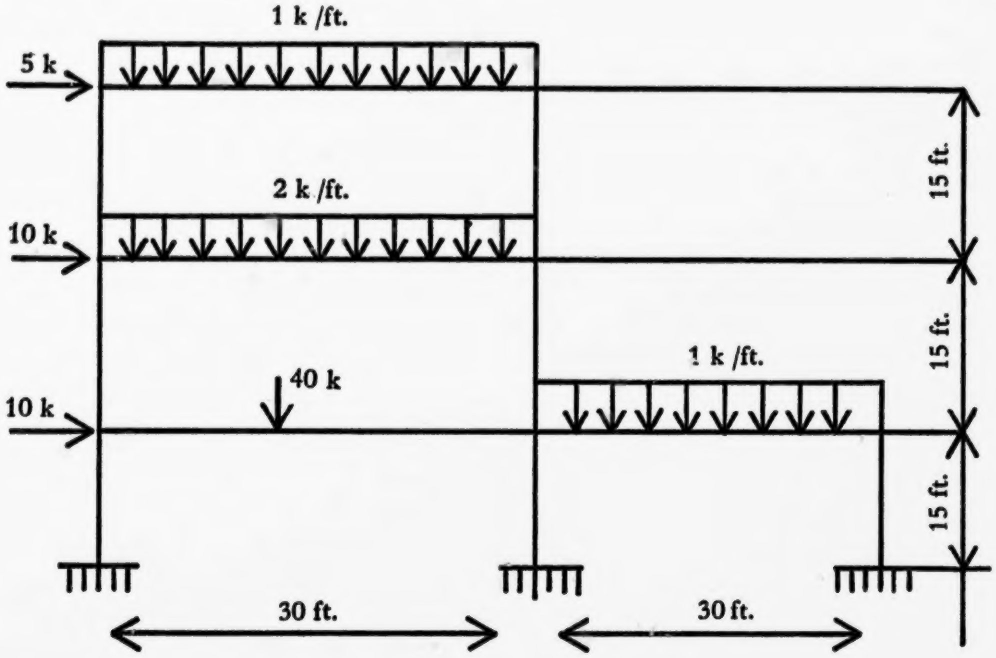
Problem. Given the two-dimensional building frame and loading shown in the figure, execute a design by selecting standard steel sections for all members of the structure. Stresses must satisfy the AISC Specifications. For simplicity, assume all members to be laterally supported. Attempt to optimize the design based on minimum weight.

Procedure. The student first makes an approximate analysis of this indeterminate structure by making behavioral assumptions (e.g., location of points of contraflexure, distribution of story shears between columns, etc.). He then analyzes this trial structure using STRESS, a general purpose program for structural analysis which uses a problem-oriented language for input. After checking stresses against allowable values, he recycles by selecting new members as required, modifying the computer input, and obtaining a new analysis. The cycling operation is continued until the student has achieved what he believes to be both a safe and an optimum design.

Instructor's comments. The purpose of this problem is to provide experience in the design of steel frames and to develop understanding of the behavior of such structures. The preliminary analysis and design is important since it permits the student to evaluate the validity of his intuitive feeling for the structural behavior.

The input may be written in 10 or 15 minutes and subsequent runs require only changes in member properties. A typical student might therefore obtain five or six runs in the course of the design, for which the equivalent of two homework exercises is normally allowed. During this process the student learns a great deal about the effect of changing member properties on the gross internal forces and the problems associated with optimizing a design.

Given Structure and Loading



Portion of Students Program

```
STRUCTURE 1.551 FRAME ANALYSIS BY NEVINS AND LYNN
TYPE PLANE FRAME
NUMBER OF JOINTS 10
NUMBER OF SUPPORTS 3
NUMBER OF MEMBERS 11
METHOD STIFFNESS
JOINT 1 COORDINATES    0.    0.
JOINT 2 COORDINATES  360.    0.
JOINT 3 COORDINATES  720.    0.
MEMBER 1 FROM 1 TO 4 PRISMATIC 14.40 0. 0. 0. 0.     272.9
MEMBER 2 FROM 2 TO 5 PRISMATIC 27.94 0. 0. 0. 0.    1063.5
MEMBER 3 FROM 3 TO 6 PRISMATIC 14.40 0. 0. 0. 0.     272.9
```

Portion of Results for Students Program

Structure 1.551 frame analysis by Nevins and Lynn, loading one

Member	Joint	Axial force	Shear force	Bending moment
1	1	48.8660450	2.2492919	298.6059227
1	4	−48.8660450	−2.2492919	106.2666206
2	2	95.9773693	14.9974674	1530.4982605
2	5	−95.9773693	−14.9974674	1169.0458984

Linguistics

Harvard linguistics 104. Computation techniques for linguistic analysis.

Linguistics 104 was given in 1965–66 and is scheduled to be given in alternate years henceforth. The enrollment this fall was 50 students of whom 40 were undergraduates. Topics discussed included: introduction to computers and programing; concordance and index preparation; authorship identification; computational techniques for historical linguistics; generative grammars; syntactic analysis by computers; discourse analysis; theories of semantics; information retrieval and question-answering systems.

Computers were used throughout this course both for demonstrations in which the students played an essentially passive observer role and for active laboratory exercises. For example, a concordance system developed at the University of California was used to illustrate techniques and problems of concordance preparation. Each student was required to become familiar with operating procedures for these programs and to submit a short text of interest to himself for concording.

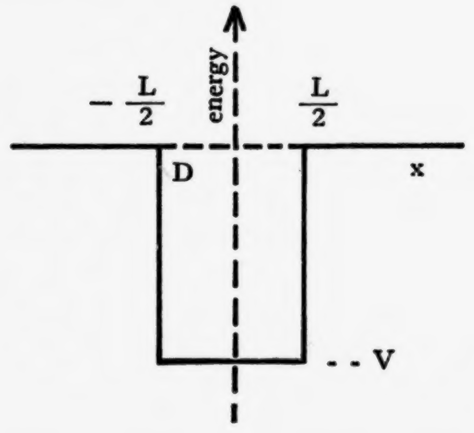
In addition, each student was asked to prepare a small English grammar and dictionary for a text of his own choosing and given an opportunity to test the operation of the grammar and the dictionary by means of the predictive syntactic analyzer developed at Harvard.

Instructors' comments: For both of these examples it would be impossible to avoid the use of a computer unless a roomful of dedicated monks were available. However, with the aid of the computer the students are able to look at patterns and see interesting phenomena that otherwise would be masked by unbearable tedium.

Physics 24, Dartmouth College.

The square-well potential: A computer assisted exercise—

A. Theory of the square-well potential. The one-dimensional square-well potential is defined by the following function:



$$U(x)=\begin{cases} V, & -\frac{L}{2}\leq x\leq\frac{L}{2}, \\ O, & \text{elsewhere} \end{cases}$$

where V is a negative number for a well and positive for a barrier. The Schrodinger Equation in one dimension is

$$-\frac{h^2}{2m}\frac{d^2\psi(x)}{dx^2}+U(x)\psi(x)=E\psi(x)$$

Exercise 1. We wish to transform this equation to dimensionless variables so that the essential parameters will become obvious. Show that if we let

$$x=\rho\frac{L}{2},\qquad E=\epsilon\frac{2h^2}{mL^2},\qquad U=u\frac{2h^2}{mL^2},\qquad V=v\frac{2h^2}{mL^2}$$

then the Schrodinger Equation becomes:

$$\frac{d^2\psi(\rho)}{dp^2}=(u-\epsilon)\psi(p) \tag{1}$$

A program has been written which integrates numerically the differential equation, equation (1), step by step starting from the center of the well, $\rho=C$, and proceeding in the positive sense. You must supply to the program a trial value for and information as to whether it is an even or an odd function you are looking for. The depth of the well is already set at -36, in our units. The program will then plot a graph of the solution, and you may observe whether or not it is a physically acceptable solution. If not, try to improve the solution with a new energy. Keep the process up until you have established the acceptable energy eigenvalue to an accuracy of four decimal places. Then look for a different acceptable eigenfunction, and repeat the process. Your objective is to produce the eigenvalues and graphs of the eigenfunctions for all of the physically acceptable bound states of this well. (Hint: There are four such states; it is easiest to start looking for the state near the top of the well.)

After you have found the four eigenvalues and graphs of the eigenfunctions, answer the following questions:

1–1. In what order do the even and odd functions appear?

1–2. Numbering the states from the *bottom* of the well, what is the relation between the number of nodes (ψ=O) and the number of the state? (Remember that the graph shows only the positive values of ρ; the other half of the graph may be inferred from the symmetry of ψ.)

1–3. In which state is the particle most likely to be in the classically forbidden region and in which state is it least likely to be there?

[The problem is then broadened to discuss the analytic solution for the eigenvalues and the calculation of the eigenfunctions. Two more computer exercises are included in addition to the theoretical analysis.]

Instructor's comments: The one-dimensional square-well is studied as a model quantum-mechanical problem because it displays many features of mathematically more complicated systems but is itself soluble in terms of elementary functions. The purpose of this exercise is to have a close look at a variety of features of this problem without having to go through the laborious work of plotting graphs of wave-functions and solving by hand the transcendental equations which arise even in this elementary problem.

The square-well exercise on the computer was intended as a counterpart, not a replacement, for laboratory experience. It afforded the student an opportunity to "experiment" with the theory involved, experimentation which would be difficult at best if computations and plots had to be hand produced. It was selected to permit a strong interplay between the theoretical or analytical solution on the one hand, and the consequences of that solution on the other hand. Not only did the students solve the square-well problem, but they saw "shapes and patterns" as well.

The students themselves felt this effort produced more learning per hour than a conventional experiment would have. The problem could also have been presented as a homework exercise, and here again would have an advantage because it was structured instead of being a random isolated exercise as is usually the case. In fact, most of the textbook material on this problem could have been skipped. This exercise required about 4 hours of console time plus about 2 hours in preparation, though some students spent up to 12 hours. This exercise had the highest response rate of any in the course.

Chemistry

Analysis of binary ammonium salts at University of Michigan.

Each year at the University of Michigan, about 100–150 students particularly proficient in mathematics are enrolled in a unified science program of courses consisting of a special four-semester mathematics sequence accompanied by a sequence of physics-chemistry-chemistry-physics courses. This program, which has been in existence since 1955, enrolls honor students whose major interests are in mathematics, physics, chemistry, and engineering.

In the third semester of the sequence, experiments are centered around a major unknown which requires about five or six laboratory periods of 4 hours duration each. A binary ammonium salt mixture has been used successfully to introduce the students to the techniques of quantitative analysis, to permit the students to examine their data in terms of the stoichiometry of the mixture, and to provide the students with a relatively large number of data to use in a statistical evaluation of their results.

The data were plotted (on semilog paper) as log counts per minute versus time. Students drew the best straight line and the maximum and minimum slopes to determine visually the uncertainty in the half life. Other students devised least squares computer programs to evaluate their data.

A computer program was written which analyzes each student's data. The computer output includes the stoichiometric calculated percentages, standard deviations of the mean, the observed probable error of the weighted mean, and the theoretical (i.e., propagated) error of the weighted mean.

The students were given these computer calculations and a mathematical description of the statistical methods used. They were provided with tables of "Student t" values for 50, 90, 95, and 99 percent confidence levels. The students, therefore, were able to convert the "infinite size" standard deviations to a percent confidence level. This proved useful in comparing the experimental uncertainties with the estimated propagated error limits. They were expected to use these calculations in their evaluation of the weight percentages and their estimates of the precision and accuracy of their data.

Instructor's comments: Because the computer is available to aid in the data evaluation, students have more time to spend on interpreting the data rather than going through rote calculations.

Geology

Geology at Pomona College, Claremont, Calif.

The following project was done by an undergraduate geology major. Consider a rectangular area subdivided into many squares. Each of the squares is to be drained in one of the four cardinal directions—the particular direction is determined randomly subject only to the restriction that closed drainage basins are to be avoided if possible. Using this as a very simple model of river systems, investigate the relationship of stream order to drainage area, stream length, and number of streams.

The computer was used to calculate and draw examples of river systems using this simple model. The drainage basins were then determined and analyzed by visual inspection. Tabulation then indicated empirically that stream order was linearly related to the logarithm of drainage area, stream length, and number of streams and that the size of the biggest basin in each of many independent drainage systems follows Gumbel's distribution.

Instructor's Comments: The classic work on this subject is by Luna B. Leopold, chief hydrologist of the U.S. Geological Survey; and a notable lecture by Dr. Leopold, in Claremont during the winter of 1965, was the immediate stimulus to this project. Although the student involved had only a limited time to devote, I believe that he gained an appreciation of Leopold's work that would have not been so easily achieved in any other way.

Social Sciences

Examples of computer use in the Social Science Division at the University of California, Irvine.

1. Psychology I, introduction to psychology.

   Psychology I is a one-quarter introductory course for both majors and nonmajors. It provides an overview of the basic facts, principles, and theories in general psychology. As an exercise in applied educational psychology, students are taught the *coursewriter* language and write small programs covering limited topics which are then tested on several of their fellow students.

   Computers are also used to provide review tests that the students may use to guide their reading and check their comprehension. For example: "psymiller", 658 instructions, covers George A. Miller's *Psychology the Science of Mental Life;* "psymotiv1, 2, 3", 655 instructions, is based on Edward J. Murray's *Motivation and Emotion;* "psypers1", 337 instructions, tests concepts of Leona E. Tyler's *Tests and Measurements;* and "psypers2", 420 instructions, is based on Richard S. Lararus' *Personality and Adjustment.* A word association experiment has also been programed, consisting of 464 instructions.
2. Economics I, introduction to principles of economics.

   Economics I is a one-quarter introductory course for both majors and nonmajors. It will concentrate on the essentials of price theory in the context of partial and general equilibrium analysis. Subject to this constraint, it will be problem oriented with emphasis on problems taken from the area of economic growth and development of comparative economic systems as well as more standard topics; e.g., theory of the firm.

   As an example of the use of the computer, the student will be given the role of a trader in a highly organized market. After being introduced to the rules of market functions, he will then work in a game where he must make production decisions. In this manner a complete general equilibrium model can be constructed and the student can acquire a strong intuitive knowledge of the model.

   The introduction to the market game follows. The dialogue is carried out between a student and a computer over a typewriter terminal.

   This chapter is the first of several which are designed to aid you in learning economics. Each will describe a situation to you and you are then to respond with either questions *or* answers—the computer will in turn respond to you. You may ask any question (or give any answer) that you believe to be appropriate.

You are a resident of a small agricultural village that is almost completely self-sufficient. The major crop is wheat, grown by the villagers both for their own consumption and to sell in a nearby market. The villagers sell the wheat that is left over after they have provided themselves with a sufficiency. They use the money that they get from the sale of wheat to provide the village with things they do not themselves produce.

You have been selected by the village to act as its trader in the market where wheat is bought and sold. (This selection is an honor, since the trader does no other job for the village.) In order to continue as trader, however, you must be a good one, or you will be replaced.

You begin your trip to the market with 1,700 bushels of wheat to sell. Upon your arrival, you find that the market place is well organized and you learn the following rules that apply to all participants.

Rule 1. Buyers (there are four of them) are required to stay in a fixed location; they may talk *only* to sellers and *must* answer seller's questions truthfully.

Rule 2. Sellers (and there are a lot of them) may roam freely and may talk to anyone, but may not conspire.

Rule 3. There is a brief initial period of 1 hour during which no sales may be consummated (called the Nodding period). At the end of this period final sales are made and the market is closed.

NOTE.—This does *not* mean that you need work at the terminal for 1 hour. Since the computer is simulating the world, it will tell you just before the "hour" is up.

You have arrived a few minutes before the Nodding period. You see to it that your 1,700 bushels of wheat are safe and begin to walk around the market square just as the bell signals the beginning to the Nodding period—you're on your own now. What would you like to know?

Instructor's comments: The main advantage of the computer's use in introductory courses is in the organized feedback to the instructor. In addition, the computer provides a modifiability not present in other methods of program organization—courses can be readily changed or adapted as the need arises.

APPENDIX K

STATEMENTS CONCERNING VALUE OF COMPUTING

JAMES F. OATES, JR.,

Chairman of the Board, The Equitable Life Assurance Society of the United States

The business of life insurance was among the first to recognize the possibilities of electronic computers and has made extensive use of these powerful modern aids. Although much of our work has been of the "cost displacement" category involving routine business operations, we are increasingly engaged in a growing number of management-oriented applications. Our business utilizes the services, among others, of actuaries, doctors, lawyers, investment analysts, economists, and sociologists, and we know from the work we have done that the capabilities, and limitations, of the computer will increasingly have to be understood and appreciated, not only as to their effects in the respective disciplines, but on overall operations.

It will become increasingly valuable for young men and young women who enter any phase of the life insurance business to understand how computers can be used in handling and analyzing data. I sincerely hope that American colleges will be able to meet this challenge. Few are likely to question the vital need for computing facilities in the study of subjects such as physics, mathematics, and astronomy. But beyond that it seems to me that the uses and advantages of computers have a direct place in such courses as business administration, social science, and teaching, and have some place in the total education of many other students.

DAVID ROCKEFELLER,

President, The Chase Manhattan Bank, N.Y.

Although electronic computers have dramatically modified the handling of banking transactions in recent years, allowing us to service more effectively the growing needs of our customers, we have only begun to realize the true value of computers. In the years ahead, they will provide bank management with timelier and broader information on a whole range of problems requiring managerial decisions.

Proper use of this new electronic tool presents a challenge to the educational community to train men and women to design and use the new systems. This training must go beyond instructing future managers in the use of computers as accounting tools, and must develop managers who can take full advantage of all aspects of the new information sciences. While some of our universities have made significant strides in this area, there is an urgent and continuing need to expand the development of this new breed of manager.

RALPH LAZARUS,
Federated Department Stores, Inc., Cincinnati, Ohio

The digital computer has already proved to be of great value in recording, controlling, and analyzing the masses of merchandise information which we require to run our increasingly complex business. It is also used more and more effectively in our analysis of current operations and seasonal budgeting.

It will become even more valuable as we learn to use its qualitative potentials for longer range knowledge, and decisions which we have to make. We should be using this tool to identify not only future needs of consumers, but also in what kind of environment and with what kind of services they will wish to make their purchases.

As we develop our organization for the future, we will be searching for men and women not only knowledgeable in the principles of management, but in the techniques of applying these principles as well. We will be looking to the universities to produce graduates with a broad spectrum of knowledge, including an understanding of the use of computers to manage a large business, both short and long range.

DANIEL V. DE SIMONE,
Director, Office of Invention and Innovation, U.S. Department of Commerce, National Bureau of Standards

It is common to say that the computer has changed our lives, that it enables us not only to do things better, but to perform tasks never before feasible to man. What is not common is the realization that the computer has given man a new freedom, which is of enormous significance to the education and fulfillment of this generation and all those to come. It has released him from the drudgery of the past and given him new opportunities to utilize his *creative* powers, as the Greeks put it in another age, along lines of maximum excellence.

It is of the greatest importance, therefore, that man be educated to harness this electronic servant, for only then will he more universally be free to develop and fulfill himself creatively. And we would hope, too, that with this new freedom, our educational system will then devote greater emphasis on stimulating the inventive and innovative potential of students, for it is not sufficient merely to teach them what the computer can do for them. They must also be taught what the computer cannot do for them.

John G. Kemeny,
Dartmouth College

Some years ago the Committee on the Undergraduate Program in Mathematics (CUPM), recommended that the first introduction to computing be part of freshman or sophomore mathematics. At that time implementation did not seem practical, but the coming of time-sharing computing systems has made it possible to implement the recommendation at Darthmouth College. We now train 650 freshmen (80 percent of the class), each year, in the rudiments of computer programing.

The program is incorporated into second semester freshman mathematics, which is calculus for the physical science students and finite mathematics for other students. In either case, students attend two 1-hour lectures and read a short manual. After this, they debug four programs, entirely on their own, with a hands-on work on a teletype input to the time-sharing system. The resulting programs are tested by the computer.

We now have a careful evaluation of this program. During the 10-week academic term, a typical student spends three-quarters of an hour per week on the teletype and an equal amount of time in planning his programs. Therefore, the entire computer training occupies only 15 hours of a student's time. In spite of the fact that such modest times are used, we are running better than 90 percent success throughout the freshman classes, and most of the students feel that they have learned enough to make use of the computer in other courses.

I am of the opinion that no other academic program yields as high a dividend, per time invested, as the freshman computer program. Even if the student never again touches the computer, he will leave the college with a sensible attitude toward the use of high-speed computers. We also know that a significant minority of the students avail themselves of time-sharing in connection with more advanced courses. The ability to assign computer problems as a matter of routine, in any course that has a year of mathematics as a prerequisite, is beginning to show a significant effect on the campus. Our engineering and business schools have made most imaginative use of time-sharing in a wide variety of courses. We also find scattered, but interesting use throughout the science and social science departments. And everyone seems to agree that the use will expand as the faculty gains more experience.

It is my personal opinion that the computer will go a long way toward breaching the gap between the abstractness of modern mathematics and practical applications. I hope that, in the future, the basic goal of mathematics education—teaching fundamental principles—will be extended to the point where a student can translate powerful mathematical logarithms into computer programs. In those cases where this has happened on the Dartmouth campus, we find that undergraduate students can solve significant research problems in a variety of applications of mathematics.

H. W. JOHNSTONE, JR.,

Professor of Philosophy and Assistant to the Vice President for Research,
Pennsylvania State University

Let me begin by agreeing with you (J. R. Pierce) that most undergraduates should be exposed to computers and computing as tools. But my own argument for such exposure is not that most students ought to learn to use the computer in order to solve practical problems, any more than I would argue that they should study scientific method in order to solve practical problems. Scientific method, in the form in which is sometimes a required course (or part of one) for all or most undergraduates, is a liberal study. Its purpose is to acquaint the student with the nature of scientific thinking, so that he will see science not as a kind of familiar magic that he takes for granted, but rather as a human achievement. In my view, a similar liberal course ought to be given on computers. The emphasis would be upon the concept of a computer and upon the general methods of using computers. The student who had been exposed to such a course would see the computer as a human achievement rather than as a black box to be taken for granted. He would see how the possibility of using computers to solve problems has revolutionized the ways in which we think about the problems. A person for whom the computer is merely something to be used gains from his contact with it no appreciation of the nature of the contemporary world. Such appreciation presupposes a certain awareness of the nature and method of the computer as such—an awareness that is quite different from the knack of programing in FORTRAN. No one could say that the course I have in mind is concerned with gadgetry.

I would say that the nature and method of the computer are philosophical ideas, like those of the nature and method of science in general. Most of the ideas presented in truly liberal courses are philosophical. The philosopher can be concerned with these ideas in a deeper way than is either the student or teacher of the liberal course. The philosopher is not content merely to expound the ideas; he is interested in stating as clearly as possible what they mean. Both the idea of the computer itself and society's assumptions about the use of the computer need analysis and clarification.

The philosopher sees culture as manmade, and indeed as an expression of man's view of his own nature. Medieval culture was the expression of the view that man is at home in the world. When science first arose in the 17th century, it was both the cause and the result of an increasing sense of alienation from the world. Man regarded himself as a creature of subjectivity, whose senses screened him from the invariant mathematical relationships that governed the universe in its infinity. Nowadays we are less sure that these relationships are invariant, less sure that the universe is infinite, and more confident in our own point of view. Some of this confidence has been won through the use of the computer. Its role in our culture is thus an expression of our view of our own nature.

At your symposium (the computer symposium presented at Bell Laboratories in June 1966), I was fascinated by the particular applications that you are making of computers. What impressed me most deeply was that in the number of these applications we have reached a turning point. The use of the computer has all at once spread to all aspects of our culture. It is this that struck me as being of primary philosophical relevance. What is relevant is the way the computer has changed the quality of contemporary life—not so much in satisfying our material needs as in causing us to think about ourselves in a new way.

H. O. Pollak,

Director, Mathematics and Statistics Research, Bell Telephone Laboratories

The two most important current facts about mathematics in the colleges and universities of the United States are the increases in the number of mathematics majors and in the total number of students enrolled in mathematics courses. The number of mathematics majors has multiplied by a factor of five in the last 10 years from 4,000 in 1954 to 20,000 in 1964. This is about three times the rate of growth of the overall student population. Similarly, from 1960 to 1965 the total enrollment in undergraduate mathematics courses has risen by about 50 percent, from 570,000 in the fall of 1960 to a guess of over 800,000 for the fall of 1965. This is one and a half times the rate of growth of the overall student population.

Now where do the mathematics majors go after they receive their bachelor's degree? First of all, about a quarter of them seem to go into computing, as either a full-time or part-time occupation. We very much owe these students a feeling for the numerical and algorithmic side of mathematics as part of their undergraduate training. Furthermore, pretty close to half the mathematics majors go on to graduate work (mostly in mathematics itself). Many of these students become secondary teachers of mathematics. Now the signs are very clear that some aspects of computer education are moving down from the colleges and becoming a part of the secondary curriculum. Many experiments are already underway—for example, the States of New York and Pennsylvania are teaching computing to some of the present teachers, and SMSG has written a high school computing course. The current plans for future curriculum reform in secondary mathematics all include the computer. Mathematicians who are most concerned with teacher preparation are now recommending that all prospective secondary teachers should learn something about computers (as well as about applications) as part of their college preparation. Finally, the use of the computer in mathematical research is also a growing phenomenon. There are many examples where new ideas for research, or a need to find a new understanding, have appeared through judicious numerical work which brought into the open quite unexpected and unexplained mathematical phenomena. It is not fashionable among research mathematicians to admit this use of the computer, but I can document many examples of it.

Despite the current growth of mathematics as an undergraduate major, most of the undergraduates taking mathematics (roughly 80 percent of the total mathematics enrollments) are students from other disciplines; i.e., prospective users of mathematics. Many of the engineers and physical, biological, or social scientists taking mathematics will apply their knowledge through the computer, and it is very necessary in teaching mathematics to these students to keep before them the relation between mathematics and computing. Thus, the teacher of undergraduate mathematics must also know something about the computer.

Future computing specialists, future secondary teachers of mathematics, future research mathematicians, future users of mathematics in other disciplines, and future teachers of undergraduate mathematics make up most of our body of mathematics students. It is clear that most undergraduate mathematics courses should contain questions, problems, and pieces of theory which are motivated by the numerical aspect of the subject. Furthermore, all mathematics majors should have an exposure to the computer.

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